A REGIONAL CLASSIFICATION OF THE SOILS OF WESTERN AUSTRALIA.*

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I.—INTRODUCTION.

The recording of scientific information concerning Western Australia is of fundamental importance for the understanding of the conditions existent in the State and for the promotion of sound development. From the point of view of the physical sciences the most important attempts which have been made include the geological maps of the State prepared by Gibb-Maitland and Blatchford of the Western Australian Geological Survey, and by David (1932), the work on minerals by Simpson, Jutson's (1934) "Physiography," Clarke's (1926) regional classification, the vegetation map of Kessell and Gardner (see Kessell, 1928) and of McTaggart (1936), and the soil map of Prescott (1931, 1933). In his account of the physiography of Western Australia Jutson has recognised and described 9 physiographic Divisions, and Clarke has subdivided the State into 15 so-called natural regions.

Each of these workers has succeeded in recording in a systematic manner observations concerning the conditions in the State, but, except for the publications by Prescott (1931, 1933), no attention has been paid to soil conditions and soil problems.

When it is appreciated that the soil type, broadly speaking, represents the integration of the most important ecological factors of biology (including both plant and animal organisms), climate, geology and relief, it is apparent that the soil is probably the best and certainly the most inclusive basis for a regional survey of any geographic unit. Consequently no apology is needed for this extension and elaboration of the work of earlier contributors.

In viewing the situation in Western Australia the soil scientist, or pedologist, is faced with the problem of mapping an area of nearly one million square miles; an area representing one of the oldest land surfaces of the globe and in which the occurrence of fossil soil horizons has multiplied the complexity normally due to the interaction of geological, climatic and biological factors.

The first map of the soils of Western Australia was prepared by Prescott (1931, 1933). Prescott provided an elucidation of the enigma when he recognised the extensive ferruginous and aluminous gravel formations, or laterite, to be the remains of an ancient B horizon of a soil—to be a fossil subsoil. These gravels occur in all parts of the State older than late

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Cainozoic, and are associated with azonal* soils of low fertility. With the recognition of the importance of these azonal soils the picture became more clear and it was possible to recognise soil zones corresponding to some of the *great soil groups* of the world.

Prescott recognised six major soil zones in Western Australia, and the zonal soils of Western Australia were found to resemble those of corresponding zones of the Eastern States. Furthermore, these zonal soil types actually formed on the exposures of country rock, on alluvial material, etc., while generally the azonal soils were typical of the higher levels where lateritic gravels covered the country rock. Observations left no doubt that they were related to this fossil soil horizon of the ancient plateau, *the Great Plateau of Western Australia,* which is now undergoing erosion under the present cycle.

More recent observations have confirmed Prescott's generalisations. They have also provided information for more accurate description and delineation of the soils of the zones, for the definition of a new major soil zone probably not developed extensively outside this State (Teakle, 1936), and for the subdivision of the zones into regions in which the recurrence of soil, ecological, and topographical conditions are very generally similar. It is the purpose of this paper to present the conception of soil regions in Western Australia and to describe such regions which have been mapped to afford a closer, yet still broad, definition of the soil conditions of the State.

II.—THE CONCEPTION OF A SOIL REGION.

Most schemes for soil classification are designed to define the unitary soil type or soil series in terms of pedogenic factors and stage of development just as plants or animals are classified, but, geographically speaking, subdivision of the great soil groups must be based on soil associations or complexes. Each association will embrace a considerable number of soil series and intrazonal soils, and in this paper has been termed a *soil region* on account of the broadness of the subdivision. Within each soil region the general topographic, climatic, and ecological conditions will be the same; agricultural, forestry, and pastoral possibilities and problems will be similar; and the area will be represented by a reasonably constant association of principal soil types. A similar attempt has been made in the preparation of a soil map of the Union of South Africa. The basic idea in the present classification, however, more closely resembles that underlying the "catena"† of Milne (1935) but is considerably more broad and each region may include a considerable number of catenary units.

In this subdivision the area of a soil region ranges from nearly 3,000,000 to over 140,000,000 acres. It is realised that for many practical purposes the unit is far too large and that, due to insufficiency of observations, the boundaries of the regions in many cases are imperfectly fixed; that in many cases the boundaries are too indefinite to be fixed accurately, as the regions may merge one into the other; but it is believed that the

* Azonal soils are those which occur in a number of zones of the area, but do not react to the soil-forming factors with the exhibition of the recognised characters of the soils of those zones.

† The term catena is used to denote a sequence of soil types, generally related to topography, forming a complex which constantly recurs throughout the area.

map and text represent a summary of existing knowledge of soil conditions in Western Australia. It will, therefore, provide a basis for future soil and ecological investigations in the State.

III.—PHYSIOGRAPHY AND GEOLOGY.

Although Western Australia has an area of 975,920 square miles and stretches from 35° S. lat. to 14° S. lat., it possesses little variety in its broad physical features and geologically is predominantly of Precambrian and Palaeozoic age. Physiographically, the area may be divided into two major physical zones: a vast plateau or tableland and a narrow, low-lying almost continuous littoral strip. A new plateau is being formed under the present cycle of erosion from the "Great Plateau of Western Australia," by dissection and truncation, and, generally, the most prominent physical features of the land mass are the monadnocks and other residuals of the previous period of planation. Certain residuals of a still earlier cycle of erosion do occur but are of small extent. Fault blocks and fault scarps occur in many localities, e.g., Stirling Range, the Darling Range, etc.

The surface of the Great Plateau was gently undulating and rose gradually from the coastline, like an upturned saucer, to a general height corresponding to about 2,000 feet above sea level at the present time. The average height would correspond to a present elevation of 1,000 to 1,500 feet above sea level. Mention should be made, of course, of the Hamersley tableland in the North-West, where Mount Bruce now attains a height of over 4,000 feet.

Except in the Kimberley Division in the extreme north of the State, the topography is generally mature or senile. Broad valleys, often characterised by salt channels and extensive salinas, bounded by rounded highlands or by gently undulating tablelands, the residuals of the Great Plateau, are typical topographic features of the greater portion of the State. These broad valleys form the "new plateau" now in course of construction.

The geological formations of the State are predominantly Precambrian. Granitoid formations, with associated basic igneous rocks such as greenstones and dolerites, are most important in the south, while in the north, Precambrian or Palaeozoic sediments with associated igneous rocks are practically continuous. The Warrawoona, Mosquito Creek and Nullagine series predominate north of the Tropic of Capricorn but are associated with important Permian deposits in the Kimberley and Gascoyne Districts. In the south, in addition to the main granitoid masses, recent research (Forman, 1937) has shown that Precambrian sediments, for example the Whitestone Series, are more important than originally recognised. In the coastal areas generally a greater variety of more recent sediments are encountered. Jurassic rocks occur generally from Derby to Perth, Cretaceous sediments are extensive between North West Cape and Gingin, Tertiary and recent deposits occur from Broome to Eucla.

Raggatt (1936) and Raggatt and Fletcher (1937), have given a valuable and detailed description of the Tertiary, Cretaceous and Permian formations of the North-West Basin and, in their discussion, include the coastal area between Murchison River and North-West Cape.

The Nullarbor Plains are composed of horizontally bedded, marine limestones of Miocene age, and the spicular sandstones and other deposits of this age have been recognised over considerable areas in the more southerly parts of the State.

IV.—CLIMATE.

Climatically, Western Australia may be divided into three provinces.

A.—The Tropical areas of summer rainfall in the north: rainfall 10 to 50 inches per annum.

B.—The temperate areas of winter rainfall in the south: rainfall 10 to 60 inches per annum.

C.—The central province of low rainfall, generally under 10 inches per annum, which serves as a buffer between provinces A and B.

Approximately half of the State falls in province C—has an average annual rainfall of less than 10 inches per annum.

Province A.

The rain generally falls in the November-April season and the mean annual temperature ranges from 75° F. to somewhat over 80° F. The Meyer ratio* ranges from 15 in the south to 100 in the extreme north. Prescott (1937) has shown that the period of moisture conditions suitable for agriculture without irrigation in the more favoured northern areas is limited to four months of the year, December to March, and, unfortunately, that the rainfall during these months is fairly unreliable when compared with places of similar climate such as Nigeria. Barkley (1931) has shown that the "Coefficient of variation"† ranges from 20 to 30 per cent. in the Kimberleys and reaches 60 per cent. in the Onslow area. Davidson (1934) reports that, on the average, precipitation in the Kimberleys exceeds evaporation only in two months, January and February, and over the great bulk of the province the monthly evaporation is always in excess of precipitation.

Rainfall per wet day is above 40 points,‡ a fact of considerable importance in soil formation, which is largely a function of the leaching properties of the precipitation.

Province B.

The south-western portion of the State, receiving an average of over 10 inches of rainfall per annum, is in the winter rainfall zone and enjoys a mild, temperate climate. From 60 to 90 per cent. of the rainfall is recorded in the April-September or "winter" portion of the year and in the drier parts of the province the "wet" season is practically confined to two months, June and July. Over the agricultural areas monthly precipitation exceeds evaporation for at least two months. The spread is June and July in the outer wheat belt and widens to the April-October period in the Frankland region, which includes the karri (*Eucalyptus diversicolor*) belt of the extreme south-west. East of Southern Cross, on the average, the monthly precipitation never exceeds the evaporation. Some discussion of these conditions has been given by Shelton (1933).

The mean annual temperature ranges from 60° F. to 70° F. Summer temperatures may be uncomfortably high during heat waves but are seldom excessive and, during the winter months, minimum temperatures

*The Meyer ratio is the annual precipitation in inches divided by the mean saturation deficit of the atmosphere in inches of mercury.

†The "Coefficient of variation" is the mean departure of the annual rainfall from the average annual rainfall, expressed as a percentage of the average annual rainfall.

‡100 points equal 1 inch.

seldom fall below 24° F. even in inland centres where continental conditions prevail. The cool, humid conditions of June and July temporarily retard the growth of crops and pastures but excellent growing conditions characterise the spring months.

The Meyer ratios range from 25 to over 250. If considered by months over the whole year a more interesting picture is obtained and shows that during the winter months highly humid conditions prevail and contrast markedly with the arid summer period. For example, the ratio of monthly precipitation to saturation deficit for Kellerberrin is of the order of magnitude of 35 during winter months of June and July, and drops to about unity during the summer period.

Perhaps one of the most important climatic features of this province is the very low precipitation per wet day. The maximum reaches 40 points in the vicinity of Busselton but the great bulk of the area receives less than 30 points per wet day; about one half of the province less than 20 points fall per wet day. This precipitation may accurately be described as light rainfall and is reflected by certain important soil conditions. The soils of the so-called "mallee" areas are but slightly leached and are typical pedocals.* Soluble salts of cyclic origin (brought in by means of the rainfall) accumulate in the subsoil, and salt lakes, or salinas, in the drier areas, and salt and brackish streams and springs in the wetter areas, are common features of agricultural significance.

Province C.

The central province is arid and in no month does the average precipitation exceed evaporation. The rainfall is low but relatively not as light as in the more southern areas, as the average precipitation per wet day ranges from 20 points in the south to 40 points in the north of the province. (The Nullarbor Plains constitute an exception.) An important fraction of the total rainfall is received in rains of over an inch which cause widespread flooding of the country. The mean annual temperature ranges from 70° F. to 75° F. and the Meyer ratio is less than 25.

The climatic conditions in this province are reviewed more fully in an earlier paper (Teakle, 1936).

It is observed that both soil and vegetation zonation of the State can be related to climatic factors—particularly the rainfall factor. The 10 inch isohyet practically marks the boundary of the eucalyptus woodland, or "mallee," zone and the acacia semi-desert scrub, or mulga zone: the 15 inch isohyet marks the boundary of the grey and brown calcareous, solonised soils of the eucalyptus woodland and red brown earths of the eucalyptus-acacia woodland zones: and the 25 inch isohyet the boundary of the wandoo (*Eucalyptus redunca* var. *elata*) and the jarrah (*Euc. marginata*) forests. Of these the 15 inch isohyet is of particular pedological interest in marking the approximate boundary between pedocals and pedalfers†—between soils with incomplete leaching and soils of complete leaching as indicated by lime accumulation in the subsoils.

V.—THE SOILS.

Before proceeding with the details of the soil classification it may be of some interest to give a picture, perhaps a rather speculative picture, of the possible soil history of Western Australia.

* Pedocals show an accumulation of calcium carbonate in the subsoil, or B horizon.

† Pedalfers are soils in which aluminium and iron accumulate in the subsoil and calcium carbonate is more or less completely removed by leaching.

During a period probably subsequent to Mesozoic times the surface of the western portion of Australia was reduced by planation to a low-lying, slightly undulating plain practically devoid of striking physical features. Probably the Porongurups, the Stirling Range and Peak Charles of the Fitzgerald Peaks represent features which had withstood this planation. During at least portion of this geological period, the rainfall must have been generous and intermittent with definite wet and dry seasons. Drainage would be restricted by the low relief causing the soil to be waterlogged during the wet season and dry at other times. The conditions would be alternately reducing and oxidising which would cause iron compounds to dissolve as reduced compounds only to be precipitated as sesquioxide on drying. Over a considerable period this climate would be conducive to the formation of leached soils, and accumulation of sesquioxides, particularly oxide of iron, would occur in the subsoil. These sesquioxide formations are known as *laterite* in Western Australia. In the opinion of the writer, soils with similar ferruginous gravel in the subsoil are forming to-day under such conditions in New Zealand. Burvill (private communication) has observed similar soil phenomena in the south-east of South Australia.

Forman (private communication) has observed iron stained concretionary pebbles having somewhat the appearance of laterite, but much softer, in the Glen Innes pine plantation area, northern New South Wales. From observations in the railway cutting at Thulimbah railway siding, South Queensland (elevation 3,000 feet; rainfall 30 inches per annum), where a similar layer is exposed, Forman is of the opinion that these concretions are in the process of formation at the present time. The profile at Thulimbah consisted of grey sandy loam, 0 - 1 foot; yellow sandy loam, 1 - 2 feet; yellow coffee rock pebbles in great numbers, giving the appearance of a typical laterite in Western Australia, 2 - 3 feet. As at Glen Innes, these concretions were softer than the laterite of Western Australia. From the observations of Bryan and Hines (1930) it seems likely that laterite is at present forming in certain soil types in the vicinity of Brisbane, Queensland.

Following planation, uplift occurred to form the "Great Plateau of Western Australia" and a new cycle of erosion, with dissection and truncation, commenced. The "new" plateau of Western Australia is now in course of formation. In the course of the erosion, huge valleys have formed over practically the whole of the area (Gregory, 1914) and the Great Plateau is represented by flat topped mesas, by such formations as the Darling peneplain and by broken and rounded residuals which form many of the so-called "sandplains" of the southern portion of Western Australia.

This new cycle of erosion has removed the laterite or sesquioxide deposits from a considerable portion of the area, forming broad valleys and low rises on which the country rock is exposed. On the exposures of country rock, alluvium, etc., considerable areas of zonal, or normal, soils, showing incomplete leaching, podsolisation and similar zonal features, are reflections of present climatic conditions. Where the laterite persists, the nature of the parent material precludes the development of the distinct zonal features of the normal soils and, consequently, azonal soils occupy important areas throughout the State. Azonal or skeletal soils of similar characteristics also form where areas of quartzites and resistant siliceous sandstones outcrop and resist the soil forming agencies.

THE MAJOR SOIL ZONES OF WESTERN AUSTRALIA.

Only normal, or zonal, soils are considered in the designation of the major soil zones of Western Australia, which are as follows:—

A. Grey, yellow and red podsolised,* or leached, soils of the temperate sclerophyll forests.

B. Red brown earths of the eucalyptus—acacia woodlands.

C. Grey and brown calcareous, solonised† soils of the low rainfall eucalyptus woodlands—(*"mallee" soil zone of Prescott*).

D. Red and brown acidic soils of the acacia semi-desert scrub—mulga, etc.

E. Brown acidic soils of the spinifex semi-desert steppes of the north-west.

F. Pinkish brown calcareous soils of the Nullarbor Plains desert shrub steppes.

G. Pinkish brown calcareous soils of the acacia semi-desert scrub, mallee and salt bush—blue bush zone.

H. Brown soils of the tropical woodlands, savannahs and grass-lands.

I. Red sands of the central desert sandhills—spinifex with desert acacias, desert gums and mallees (*Eucalyptus* spp.)

These major soil zones are subdivided into one or more soil regions, the features of which are briefly summarised in the recapitulation, pages 186-188.

It is the purpose of this paper to describe these zones and the regions within them in the light of field and laboratory information available. The distribution and location of the zones and regions are shown in the accompanying sketch map.

A.—ZONE OF GREY, YELLOW AND RED PODSOLISED, OR LEACHED, SOILS OF THE TEMPERATE SCLEROPHYLL FORESTS—12,930,000 ACRES.

Podsolised soils are essentially soils of humid conditions in cold to temperate regions, in which leaching has completely removed calcium carbonate and calcium sulphate, has induced an acidic reaction and has brought about a segregation into distinct horizons. Development generally takes place under forest (particularly coniferous) and heath and on sandy materials poor in basic constituents.

The typical podsol of Europe, America and New Zealand exhibits three essential horizons. The A, or eluvial horizon, consists of a layer of acidic peaty material underlain by a greyish bleached layer of mineral material. Below this is the B, or illuvial, horizon, characterised by accumulation of humus and sesquioxide as well as clay. The B horizon rests on the C horizon, or parent material.

*Podsols are essentially soils with a grey surface rich in organic matter resting on a bleached subsurface, or A_2 horizon. The subsoil, or B horizon, is generally yellowish due to sesquioxide accumulation. Leaching has been complete. Podsolised soils are completely leached but may not show these typical podsol features.

†Solonised soils have an accumulation of sodium and/or magnesium in the replaceable base fraction.

In Western Australia podsolised soils form under either a eucalyptus forest or a heath and the profile is generally more or less imperfect. Except where drainage is restricted and the soils belong more closely to the hydromorphous group, the peaty layer is not developed on Western Australian podsols but many soil types do exhibit other podsol characteristics. On the other hand, in many soil types of the zone other important podsol features are absent or poorly developed. These soils must be described as podsolised and the soil zone as one of "podsolised soils."

Geologically, the area may be described as a granitic mass intersected by basic dykes and segregations, capped with laterite and somewhat dissected. The coastal areas form a fringe of Tertiary and Post-Tertiary deposits and Permian deposits assume extensive proportions south of Busselton. Smaller areas of Permian rocks, important on account of coal measures, occur in the neighbourhood of Collie.

The Darling escarpment is a fault line which constitutes the most important physiographic feature and runs from north of Gingin to south of Nannup in approximately a straight line. The granitic hills of the escarpment rise abruptly from the coastal plain to a height of about 1,000 feet and form the western edge of an undulating peneplain.

The climate is mild, very wet in the winter and dry in the summer. The average annual rainfall ranges from 25 to 60 inches and along the south coast it is moist enough during the summer period to allow the growth of hardier perennial pasture species. Davidson (1934) has shown that precipitation exceeds evaporation for five to seven months of the year.

The zone carries the chief forest formations of the State and is noted for the important hardwoods, jarrah (*Eucalyptus marginata*) and karri (*Euc. diversicolor*). The associations may generally be described as sclerophyll forests of such timbers as jarrah, marri (*Euc. calophylla*), tuart (*Euc. gomphocephala*) and wandoo (*Euc. redunca* var. *elata*), with Proteaceous, Leguminous and other shrubs, and wet sclerophyll forests of karri with wattles, *Trymalium spp.*, etc. Some 3,000,000 acres of these forests are reserved as State Forests.

As mentioned above, the soils are of the podsolised type. Zonation is largely obscured by the overwhelming prevalence of laterite and lateritic gravel on which soil formation is distinctly inhibited.

Apart from the various shades of grey, the most characteristic surface soil colour of the zone is undoubtedly yellow. The most common subsoil colour is some combination of yellow and the surface soil in many instances shows the influence of the yellow colour. Certain types of sandy soils show a shallow surface of a yellowish grey colour and a bright yellow subsoil; the ferruginous gravelly types are predominantly yellowish in colour.

A similar occurrence of yellowish soils has been observed in the Silurian hills of Victoria between Melbourne and Albury, and in New South Wales yellow soils predominate between Albury and Henty on the Interstate Railway line. Bryan and Hines (1930) describe the soils forming on sandstones, shales and other acidic rocks in the vicinity of Brisbane as "yellow earths."

For these soils the designation "yellow podsolised soils" is proposed. Proper characterisation of these soils is at present impossible but the work of Hosking and Burvill (1938) suggests a narrow silica: sesquioxide ratio, and that they are low in humus and nitrogen. They are not truncated soils.

Podsolised soils with a grey brown surface may also be observed both in this zone and in the red brown earth zone. It is possible that they are related to the grey brown podsolised soils of the eastern part of the United States of America.

Acidic red earths are characteristic of basic rocks and basic segregations (Hosking and Burvill (1938)), and are very important agricultural soils in the most productive districts.

Intrazonal soils of the zone include the rendzina, represented by the Gingin clay forming on Cretaceous chalk, (Hosking and Greaves, 1936), and the solodi*, which forms on flats liable to winter flooding and salt accumulation. This solodi characteristically carries a woodland of *Casuarina glauca*. The profile consists of a dark grey surface loam on a grey clay hardpan. The reaction is acidic: for example, at one site the surface had a reaction of pH 6.6 and the subsoil pH 6.0. This solodi type also occurs generally under similar conditions in the red brown earth zone.

The zone has been divided into three regions—

1. Swan littoral region of coastal sandhills, and clay flats adjacent to the range.
2. Darling peneplain region where gravelly soils are characteristic.
3. Frankland region: karri, jarrah and marri forest soils and wet heaths of the southern areas.

1.—SWAN LITTORAL REGION: 1,400,000 ACRES.

The west coast south of about 31°S is fringed by a littoral belt from 10 to 25 miles wide bounded on the east by the Darling escarpment or fault line. Granites, basic dykes and Precambrian metamorphosed sediments of the peneplain are sharply in contrast with the great depths of Tertiary and Mesozoic deposits of the littoral. These sediments form an artesian basin and bores have proved them to be in excess of 2,000 feet thick. Over much of the region, aeolian sand dunes, fixed by a sclerophyll woodland, cover the sediments and, unfortunately, provide but poor material for soil formation.

The climate is good; the average annual rainfall ranges from 30 to 40 inches, of which 80 per cent. falls in the winter period, and frosts are rare and seldom severe.

The vegetation may be described as a sclerophyll forest with an undergrowth of sclerophyll shrubs. Marri (*Euc. calophylla*) is generally characteristic of the better soils and jarrah (*Euc. marginata*) of the poorer types. Banksias, casuarinas and *Euc. Todtiana* grow on the poorest and most leached sands. Tuart (*Euc. gomphocephala*) characterises the coastal limestone areas.

The soils are best described in relation to three main sub-regions into which the Darling littoral region naturally falls.

a. *The talus soils.*

A narrow talus area forms the transition between the escarpment and the coastal plain. The slopes are generally not steep and the soils are generally gravelly—that is, they show a considerable amount of lateritic gravel

*The solodi is usually regarded as a solonised soil, or one which has been subjected to solonising influences, which has been acidified by leaching.

in the upper layers. Boulders of laterite have been reported in some localities. Grey sand forms the surface soil in some instances but the more general profile is a yellowish or greyish yellow gravelly sandy soil with a yellowish clay or gravelly clay subsoil. Reddish soils, as at Armadale, reflect the effect of special geological formations.

Pasture production and grape growing are the chief agricultural pursuits.

b. *Grey, grey brown and chocolate soils of the flats.*

The talus soils abutt abruptly on to the podsolised and slightly podsolised soils of the flats which consist of a belt of recent alluvial deposits some 130 miles long in a north-south direction and 4 to 7 miles wide. Prior to the provision of more adequate drainage the short coastal rivers flooded these flats and deposited layers of clay, sands and gravels as they overflowed their banks. Consequently, many of the stream channels are raised and the soils are forming on a complex and variable series of deposits.

The subsoil is characteristically a yellowish clay, often showing interposed layers of sands and gravels, and usually rests on a grey and red mottled stiff clay at a depth ranging from 6 to 10 feet. Considerable variation is observed in the surface layers which range from rich chocolate loams and grey brown sandy loams to leached grey sands more typically podsolised. Some areas are characterised by "claypans" or broad, shallow depressions perhaps one to two feet below the general level of the country. These greatly interfere with the development of the country.

The soils of this sub-region are among the most fertile in the State and are relatively rich in phosphate, potash and lime. The reaction usually ranges between pH 5 and pH 6 but samples between pH 4.5 and pH 5 have been examined. Table 1 gives a summary of the chemical composition of representative soils from Harvey, and the reactions of unlimed soils of the sub-region are indicated by the data in Table 2.

Development of this sub-region has been made possible largely by improved drainage to remove the excess winter water and the area will probably become the most intensively settled agricultural area of the State. Irrigation is being established over much of the area and rapid extension of the area watered is promised in the future as greater efficiency is attained in the present irrigation districts, and as new schemes are brought into being, either using the hills water or water pumped from the artesian or sub-artesian basin. In the northern part of the sub-region grape growing predominates and citrus, stone fruits and pastures are important. Pasture production, at present largely for dairying, is the chief industry in more southerly portions. Fat stock, horse breeding, citrus and potato production are industries of some magnitude.

c. *The Sandhill Soils.*

The coastal areas are notoriously sandy. For a distance of from 5 to 20 miles inland a sandhill formation, clothed with timber and heath, prevails and presents a generally uninviting range of soil types to the agriculturist.

These sands have apparently been blown inland from the coast.

The more inland soils are generally non-calcareous, probably as a result of a longer period of leaching, often exhibit evidence of buried profiles as a result of wind action, and carry a sclerophyll forest of jarrah and marri

TABLE 1.

Distribution Table showing the Composition of Samples from 23 Sites in in Citrus Orchards in the Harvey Irrigation Area. Sampled January, 1918, by the Department of Agriculture and analysed in the Government Chemical Laboratory. (Explosives and Analytical Department File 52/18.)

NUMBER OF SAMPLES IN EACH RANGE.

—	Total Nitrogen.								
Range (per cent. nitrogen) ...	Below ·01	·01–·03	·03–·05	·05–·10	·10–·30	·30–·50	·50–1·00	Above 1·00	
Surface soil	...	...	2	7	14	...	...	...	23
Subsoil 12 inches deep ...	1	13	6	3	...	...	...	...	23
Deep subsoil 30 inches deep ...	...	18	2	3	...	...	...	...	23
—	Phosphoric Oxide (P_2O_5). (Soluble in Concentrated Hydrochloric Acid.)								
Range (per cent P_2O_5)	—	Below ·01	·01–·02	·02–·04	·04–·06	·06–·08	·08–·10	Above ·10	
Surface soil	...	...	...	3	3	6	5	6	23
Subsoil 12 inches deep ...	...	...	1	5	12	5	...	...	23
Deep subsoil 30 inches deep ...	...	...	...	14	5	4	...	...	23
—	Potash (K_2O) (Soluble in Concentrated Hydrochloric Acid.)								
Range (per cent. K_2O) ...	—	·01–·03	·03–·05	·05–·10	·10–·30	·30–·50	·50–1·00	Above 1·00	
Surface soil	...	...	7	9	7	...	...	...	23
Subsoil 12 inches deep ...	...	1	8	14	...	...	...	...	23
Deep subsoil 30 inches deep ...	...	1	13	8	1	...	...	...	23

TABLE 1—*continued.*

—	LIME (CaO) (Soluble in Concentrated Hydrochloric Acid.)								
Range (per cent. CaO) ...	Below ·10	·10–·20	·20–·30	·30–·40	·40–·50	·50–·60	·60–·70	Above ·70	
Surface soil	...	4	4	5	5	2	3	...	23
Subsoil 12 inches deep ...	4	12	5	1	1	...	...	...	23
Deep subsoil 30 inches deep ...	6	13	3	1	...	...	...	...	23

TABLE 2.

Distribution Table showing the Reactions of Soils of the Harvey-Brunswick Irrigation Areas. (As far as is known these soils have never been limed.)

—	Number of Samples in each Range.									Total Number of Samples.
Range of pH Values	Below 4·8	4·8–5·0	5·0–5·2	5·2–5·4	5·4–5·6	5·6–5·8	5·8–6·0	6·0–6·5	Above 6·5	
Surface to 3 to 5 inches deep ...	1	7	9	17	27	16	8	4	...	89
Subsurface 3 to 5 to 12 inches ...	...	1	8	11	14	20	13	9	1	77
Subsoil 12 to 48 inches	...	1	2	2	...	7	4	3	1	20
Deep subsoil below 48 inches ...	...	2	5	4	6	4	4	3	3	31

associations. *Banksia grandis, B. Menziesii, B. attenuata, Casuarina Fraseriana* are typical small trees. The profile is more or less uniformly sandy and consists of a greyish surface sand on a yellow sandy subsoil. The depth of the surface horizon ranges from a few inches, when the grey is tinged with yellow, to several feet.

More highly leached soils occur in patches. These are white sands, often with humous coffee rock about the level of the water table, and usually carry a stunted vegetation of *Eucalyptus Todtiana, Adenanthos cygnorum,* etc.

The more coastal areas are generally calcareous at depth. Extensive deposits of forameniferal sands occur all along the western coast. These have been blown inland and by solution and precipitation have consolidated to form aeolian limestones. Fringing the coast, where the limestone or lime sand is often just under the surface, a heath vegetation usually occurs but further inland the lime has leached to greater depths—often many feet—and on these soils are found the valuable tuart (*Eucalyptus gomphocephala*) forests. The tuart soils are brownish to greyish on the surface. Where the limestone is within a few feet of the surface the subsoil is usually pinkish in colour but where a greater depth of soil occurs a brownish yellow colour characterises the subsoil.

These sands are very low in plant foods. Kessell and Stoate (1938) give the results of analyses which may be summarised as follows:—

—	Number of Samples in each Range. (p.p.m. in the dry soil.)							
Range ...	0–10	10–20	20–40	40–60	60–80	80–100	100–200	above 200
P_2O_5* ...	18	4	2	...	...	1	6	...
K_2O* ...	4	7	10	3	...	3	1	3

	(per cent. in the dry soil.)					
Range ...	below ·001	·001–·005	·005–·010	·010–·050	·050–·100	·100–·500
CaO* ...	4	6	2	9	4	2
Total nitrogen	4	7	4	10	3	...

	(pH value.)				
Range ...	below 5·0	5·0–5·5	5·5–6·0	6·0–6·5	6·5–7·0
pH	2	6	8	12	4

* Soluble in concentrated hydrochloric acid.

A characteristic of these soils is a concentration of calcium in the surface layers. For instance, the average CaO content of surface and subsurface samples from 10 sites reported by Kessell and Stoate (1938) is 0.183 per cent. and 0.086 per cent. respectively. Deeper subsoil layers are even poorer in calcium. Likewise, as is usual, nitrogen is richer in the surface layers. Phosphate shows a similar relationship but is less consistent; potash shows less tendency to surface segregation than the other constituents. Undoubtedly this surface concentration of plant constituents is due to the decomposition of leaves and litter from the vegetation. It is probably necessary to maintain a crop—forest or agricultural—on such soils to prevent the breaking of this plant nutrient cycle and the loss of valuable minerals by leaching and drainage from bare land.

In their studies on the growth of exotic pines, Kessell and Stoate (1938) find that the phosphoric oxide (P_2O_5) content of the soil is a good indicator.

Pinus radiata requires 400 p.p.m. P_2O_5 in the surface and subsurface soils or 300 p.p.m. to a depth of two to three feet for satisfactory growth.

Pinus pinaster requires a P_2O_5 content of not less than 150 p.p.m. for satisfactory growth. They find also that on the poor soils the pines respond to treatment with superphosphate in the early stages, and zinc sprays on young plants on certain soil types are curative of certain nutritional disorders.

Innumerable marshes, swamps and poorly drained basins occur in these sandhills and probably occupy about 5 per cent. of the total area. They have been described in some detail by Teakle and Southern (1937a, 1937b), who show that there are several types of which the following are the most important:—

(a) Acidic peaty sands and loams.

(b) Highly acidic colloidal peats.

(c) Marly peats.

In the Gingin and Dandarragan districts interesting intrazonal soils occur on Cretaceous chalks, greensands and sandstones. These are excellent pasture and lupin soils and form the basis of an important stock raising industry. A stock disorder of these districts, enzootic ataxia, has recently been shown by Bennetts and Chapman (1937) and Bennetts (1937) to be associated with a very low copper content in the liver and blood of affected animals and to be prevented by salt licks containing small amounts of copper sulphate.

The chief soils of the Gingin area have been mapped by Hosking and Greaves (1936), who show that a rendzina, the Gingin clay, the red coloured Whakea sand and the greyish Minjil sand are the chief types. While the light textured soil types were found to be low in plant nutrients, the heavy textured soils generally were well supplied with, and in some cases exceptionally rich in, phosphate and potash. The replaceable bases showed the clays to be of the calcium and calcium-magnesium types. Sodium was very low in the replaceable base fraction.

2.—DARLING PENEPLAIN REGION: 3,900,000 ACRES.

The region is essentially dissected granitic peneplain. The surface has been laterised and in the course of subsequent erosion much of the capping has been broken and disintegrated into a ferruginous gravel. This

ferruginous gravel occurs in practically all soils except in relatively small areas in the deeper valleys such as the Blackwood and Preston Rivers. The ferruginous gravel has influenced the soil forming processes and retarded the development of many podsolic characters. It has promoted the extension of the yellow colour of the subsoil into the surface layers. Where a light sandy surface overlies the gravelly layer, the bleached subsurface (A_2 horizon) and other podsolic features may be apparent.

The Darling peneplain is characteristically covered by the jarrah bush. On the more gravelly soils jarrah (*Eucalyptus marginata*) predominates, but where better soil conditions occur marri (*Euc. calophylla*) enters the association and often predominates. In the valleys, blackbutt (*Euc. patens*) is characteristic, and Clarke and Williams (1926) have observed wandoo (*Euc. redunca* var. *elata*) to be associated with the brown and chocolate soils on dolerite dykes in the escarpment area in the neighbourhood of Perth.

While it is impossible to describe one profile characteristic of the region the most important soil types generally show a yellowish clay subsoil, often gravelly and frequently showing a short fracture when being moulded. Grey and red mottlings frequently show in the deeper layers of the B horizon. The surface may be a yellowish grey gravelly sand to sandy loam or a grey sand with or without gravel. In some areas immature, granitic soils of low fertility are encountered and on the basic dykes and segregations, red acidic soils are usual and constitute the basis for much of the agricultural development.

Soil analyses reported by Kessell and Stoate (1938) show that the soils of this region range from very poor types, as were studied in the Pardelup area, to soils quite normal with respect to constituents other than phosphoric oxide. A summary of their data, treating all samples as units no matter what horizon the profile they represent, is as follows:—

——	Number of Samples in each Range. (per cent. in the dry soil).									
Range	below ·01	·01 to ·03	·03 to ·05	·05 to ·07	·07 to ·10	·10 to ·20	·20 to ·40	·40 to ·60	·60 to 1·00	No. of Samples.
Total Nitrogen....	....	14	17	12	8	18	4	....	....	73
P_2O_5*	17	36	16	2	1	1	....	....	....	73
K_2O*	15	13	6	9	16	12	2	....	....	73
CaO*	12	13	9	2	4	15	13	2	2	72

* Soluble in concentrated hydrochloric acid.

Agriculturally, the region is developed principally for pasture purposes and horticulture. Subterranean clover grows throughout the region and is the basis of the dairying and sheep industries. Apples are by far the most important fruit crop. It is also the home of the jarrah forest which is being maintained in production under a vigorous forest policy.

3.—FRANKLAND REGION: 4,630,000 ACRES.

Along the south coast between Albany and Cape Leeuwin the average annual rainfall ranges from about 35 inches to 60 inches and the summer conditions are cooler and more moist than in any other part of the State. Certain vegetation associations (karri (*Euc. diversicolor*)) approach the rain forest and large areas of wet heath country occur.

The principal geological formations are the granitoid or gneissic rocks with extensive basic segregations, and poor sands many areas of which belong to the Plantagenet series. Basalts are reported in isolated places along the coast.

The coastal areas may be described as estuarine deposits of Plantagenet beds out of which rise "islands" of country rock. The wet heaths with shallow surface peaty accumulations have formed on the sands of the Plantagenet beds, and in shallow depressions or "lakes" various types of peaty deposits have developed. On the "islands" of country rock which are often of very considerable area, jarrah and marri forest formations occur where the soil are gravelly or highly podsolised. Where there is less gravel, less evidence of leaching and where basic segregations occur, karri forest is in evidence.

The inland areas of the region may be regarded as the break between the Darling peneplain and the coastal areas. Considerable dissection has taken place and the physiography is definitely immature. Lateritic and gravelly soils associated with jarrah and marri forest associations occur generally on the higher levels, and where erosion has exposed the country rock and in the valleys a karri association is usual.

The soils of the Denmark area, which have been described in detail by Hosking and Burvill (1938), may be taken as representative of the region. In this survey thirteen soil types, grouped in nine series, were identified and examined, and five groups of swampy, alluvial and other complexes were distinguished. Chemical analyses show the soils to be generally low in plant foods and quite variable. The highly leached types such as the Plantagenet, Kordabup and Kwilalup soils are highly acidic but the main soil types are more favourable in reaction as they generally range from pH 6 to pH 7.

A summary of these data is given in Table 3.

Analysis of the replaceable base fraction shows the soils to be more or less unsaturated and generally 40 to 60 per cent. of the total exchange capacity consists of hydrogen. Calcium is next in importance with a general range of 25 to 45 per cent. and magnesium is fairly high in the Koorundurup and Koorrabup series. Sodium and potassium are low in practically all cases. The analysis of the subsoil clays of Denmark soils generally shows a low silica: sesquioxide ratio (0.5 to 1.8) and a low silica: alumina ratio (0.7 to 1.9). In keeping with these facts, the base exchange capacity is very low as it generally averages about 15 milliequivalents per 100 gms. clay.

Hosking and Burvill (1938) have related the reddish and chocolate coloured soils of the Scotsdale and Koorundurup series, which are formed on basic rocks, to certain red soil types of the American Piedmont belt. The Wakundup and Koorrabup series appear to be related to the grey brown podsolic soils and the yellow soils of the eastern United States of America.

The occurrence of enzootic marasmus, a wasting disease of cattle and sheep in the Denmark district, led to intensive studies by Filmer and Underwood on the nutritional aspects and by Hosking and Burvill (1938) on the soils. Underwood (Underwood and Filmer, 1935) succeeded in demonstrating that cobalt deficiency was the cause of this disorder and the soil survey established the association of the Wakundup series with the incidence of the disease. Harvey (1937) collaterally showed that the cobalt content of the Wakundup series is low in comparison with recognised "sound" soils of the area and with soils of other districts. The surface soils of the Wakun-

TABLE 3.

Showing the Medial Values for Soil Reaction, and Nitrogen, Potash and Phosphoric Oxide content, of representative Soil Series of the Denmark Soil Survey (Hosking and Burvill, 1938.)

	pH.			Nitrogen (per cent. in dry soil).		Potash (K_2O) (per cent. in dry soil).		Phosphoric Oxide (P_2O_5) (per cent. in dry soil).	
Horizon	A_1	B	BC	A_1	A_2	A_1	A_2	A_1	A_2
Soil Series—									
Scotsdale	6·7	6·9	6·3	0·21	0·08	0·057	...	0·028	...
Wakundup	6·3	5·8	5·3	0·32	0·07	0·034	0·028	0·022	0·013
Koorundurup	6·1	6·0	5·3	0·17	0·06	0·058	0·099	0·012	0·007
Koorrabup	6·0	6·0	5·5	0·16	0·03	0·019	0·011	0·011	0·004
Kordabup, Kwilalup and Un-named	5·0	5·3	4·9	0·15	0·05	0·041*	0·038*	0·008*	0·005*
Plantagenet and Willbay ...	4·4	4·8	...	0·84	0·02	0·018	...	0·006	...

* Omitting the un-named sandy loam which is very rich in potash and much higher in phosphoric oxide than the other two series in this group.

dup series average 0.8 p.p.m. cobalt (11 samples) in comparison with 3.8 p.p.m. cobalt (6 samples) in the generally sound Scotsdale series, and 9.6 p.p.m. cobalt—range 0.5 to 40.0 p.p.m. (24 samples)—for soils representing other parts of the State where cobalt deficiency in stock has not yet been recognised.

Unpublished data regarding the soils of the Manjimup area show that the main profile features are similar and the principal soil types closely resemble those of Denmark.

Valuable areas of peaty swamp land occur in the eastern coastal parts and are being used for potatoes, truck crops and pastures. The swamp lands fall into three main types: (a) marly peats, (b) acid peats and sandy peats. The modal reaction of these soils is about pH 4 but considerably higher degrees of acidity have been reported (Teakle and Southern, 1937), (c) greyish acid muck soils with a modal reaction range of pH 4 to pH 5.

Agriculturally, the region is developed for dairying, fruit growing, potatoes and truck crops, and is proving very satisfactory for tobacco on certain valley soil types in the Manjimup, Pemberton and Walpole districts. Sheep raising for the meat market offers promising returns. Forestry is of considerable importance on account of the valuable karri timber. The propitious climate renders the prospects for further development very satisfactory, but success will depend upon the solution of nutritional problems with stock and plants. The necessity for cobalt to maintain the health of stock on certain soil types is well known, and copper and manganese in addition to the usual fertilising ingredients are proving valuable adjuncts for potatoes, pastures, and truck crops on certain soil types. Drainage is required on much of the wet heath country.

B.—ZONE OF RED BROWN EARTHS OF THE EUCALYPTUS-ACACIA WOODLANDS—27,460,000 ACRES.

The red brown earths defined by Prescott (1931) occur as a zone between the highly leached or podsolised soils and the pedocals represented by the grey and brown calcareous, solonised soils. The average annual rainfall ranges from 15 to 25 inches, is of winter incidence and sufficient leaching power to have removed calcium carbonate and soluble salts from the subsoil except in the heaviest soil types. The typical profile consists of a brown to red brown surface or A horizon with a reddish subsoil or B horizon showing clay accumulation. Calcium carbonate is observed in the deeper subsoil in some instances in Western Australia, but is much less common than in the red brown earths of the Eastern States. Generally the subsoil is non-calcareous but slightly alkaline to alkaline in reaction so that the colloids should be almost base saturated. The surface soil is generally neutral to slightly acidic in reaction. (See Tables 5 and 6 below.)

Within the red brown earth zone, however, extensive areas of normal grey and grey brown soils with yellowish or greyish subsoils occur and reflect greater leaching and, in many cases, different parent materials. Furthermore, the greyer soil types are far more prevalent in the southern part of the zone than in the northern regions—apparently the result of a temperature effect as red colours appear to develop more readily under higher temperatures. Greyer soils develop on the more acidic rocks and on pipeclay formations which occur in the southern areas. These soils generally resemble the browner types in reaction values.

Lateritic gravel is common throughout the zone. It occurs in massive form on the mesas which carry mallet (*Eucalyptus astringens*), wandoo (*Euc. redunca* var. *elata*) and poisons (*Oxylobium, Gastrolobium*), but is generally in the form of gravel in the more eroded areas. It is more abundant at the higher levels.

This lateritic gravel occurs, but is uncommon, in the brown and red brown soils and in many of the grey soils forming on country rock of similar strata. In some cases this is obviously adventitious material from the original laterite capping but, where drainage is somewhat impeded, leading to periodic waterlogging, a certain amount of ferruginous gravel appears to be forming in the subsoil at the present time as a result of normal pedogenic processes. Similar occurrences of ferruginous gravel have been observed in the Cowra District, New South Wales, in New Zealand, etc. (See discussion on p. 128.)

Soils of the lateritic gravelly material are generally more yellowish in colour and often exhibit shades of pink, particularly where what appears to be a lithomarge is exposed. Wandoo and sclerophyll scrub are typical of these types, which occupy practically a continuous belt on the wetter fringe of the zone.

A small area of a heavy textured black earth, with a calcareous subsoil, has been observed on a highly basic dyke in the Pallinup area and represents an intrazonal type.

Reference has already been made to the occurrence in this zone of solodi soils on saline flats subject to inundation during the winter months. These soils are slightly acidic in reaction, are characterised by a grey clay hardpan and carry a woodland of *Casuarina glauca*.

Deep sandy soils are frequently associated with a woodland of *Casuarina Fraseriana.*

The principal geological formations of the zone are granitic rocks and gneisses with basic dykes. In the southern areas the Stirling Range quartzites affect the soils and there is evidence of other metamorphosed rocks which modify the course of soil formation. The country is typically hilly —rounded hills are characteristic, but many flat topped mesas occur in the southern regions.

Most typical vegetation associations are york gum (*Euc. foecunda* var. *loxophleba*) and jam (*Acacia acuminata*) woodlands which are well grassed and are the most prized farming lands of the zone. York gum grows on the stronger and heavier textured soils and jam on the lighter soils. Wandoo sclerophyll woodland is common south of Moora and constitutes a region. As has been mentioned, mallet is typical of the mesa slopes south of Beverley. Salmon gum (*Euc. salmonophloia*) and morrel (*Euc. longicornis*) woodlands occur in a number of places and are of considerable agricultural value in the Moora, Wagin and Katanning districts. South of Katanning morrel is known as "poot" and grows on the strongest farming lands.

Sand heaths are common throughout the zone, particularly north of Northam. Deep sandy types, gravelly types and sandy types with a yellowish gravelly and clayey subsoil occur. The latter is of considerable agricultural value if liberally dressed with superphosphate. Poison plants are often a trouble with stock, particularly in the wandoo woodlands.

Agriculturally, the zone is most important for stock raising in conjunction with cereal production. Sheep, fat lambs, pigs, cattle and horses are raised: oats for stock feed, and wheat and oats for hay and grain are produced throughout the area. First early and midseason subterranean clover (*Trifolium subterraneum*) do well in the wetter portions, lucerne for grazing is grown in the south, and wimmera rye grass (*Lolium rigidum* var. *subulatum*), *Phalaris tuberosa* and perennial veldt grass (*Ehrharta calycina*) are valuable supplements to the native grasses (*Festuca* spp., *Stipa* spp., etc.).

Of recent years an undesirable weed known as crow's foot (*Erodium botrys* and spp.) has invaded many sown pastures, particularly subterranean clover pastures, and is causing considerable reduction of grazing value on some farms.

Stock water is readily obtained in wells in the northern areas but dams are relied on to a great extent in the south.

Most districts suffer from the development of salinity in creeks and low-lying areas. This affects the supply of stock water and renders a small amount of country unsuitable for cultivated crops. The problem results from a rise in the salt water table and the development of saline springs following the clearing of the timber, which greatly increases the amount of percolating subsoil water.

The concentration of the rainfall in the winter months, with resultant waterlogging of many soil types especially in wet seasons, presents a problem in farm management. The months of June and July are generally excessively wet, and with low temperatures prevailing, pasture and crop growth is greatly retarded until the spring flush. Means have not yet been found of accelerating growth during the cold, wet winter months.

The red brown earth zone has been subdivided into five regions.

*4.—DWARDA REGION: 4,600,000 ACRES.

The Dwarda region is essentially a wandoo (*Euc. redunca* var. *elata*) woodland associated with lateritic gravelly soils and is really transitional between the red brown earths proper and the more highly leached or podsolised soils. The surface soils are generally slightly acidic, grey or yellowish grey in colour, and sandy or gravelly in nature, and have a yellowish or greyish subsoil. This subsoil is generally gravelly and shows an accumulation of yellowish and greyish gritty clay, often showing red mottlings. Many of the soils are very shallow and immature.

Waterlogging is frequently prolonged during the winter months. This condition apparently gives rise to a siliceous cement as the subsoil cements badly on drying out in the summer.

The Northern portion of the region is undulating to hilly, but south of Katanning the country is relatively flat. Many of these flats show poorly drained portions on which swamp yate (*Euc. occidentalis*) is characteristic. Yate (*Euc. cornuta*) grows on the higher land. A typical profile in these areas shows the following features:—

Surface:—Brownish grey gritty sand to sandy loam.

Subsoil:—Pale yellow to yellow sandy loam to gritty and sandy clay showing red mottling with depth. Cements badly on drying out in the summer.

* The regions are numbered in sequence 1-33.

Analyses of samples of soils from Cranbrook and which show these features are given in Table 4. Brown and red brown soils of heavier textures occur in patches throughout the area. These show the more typical red brown earth colours and are frequently associated with basic dykes and segregations.

This area south of Katanning could well be described as a sub-region. It is well known for the production of stud merino sheep.

The region is primarily suited to pasture and forage production with attendant stock raising and to forestry—particularly for the growth of mallet (*Euc. astringens*) and wandoo for tannin supplies. Many portions of the area are badly affected by poisons of which box poison (*Oxylobium parviflorum*), York road poison (*Gastrolobium calycinum*), cluster poison (*G. microcarpum*), sandplain poison (*G. oxylobioides*) and bullock poison (*G. trilobum*) are commonest and most serious hindrances to stock raising. The soils are naturally of low fertility chemically but after being built up with subterranean clover and superphosphate are proving more suitable for grass establishment.

TABLE 4.

Analyses of Soils from the Cranbrook Area. The country originally carried Wandoo, Yate (Euc. cornuta), Shrubs, Grasses, etc.

Serial. No.	Depth inches.	Organic Carbon.	Total Nitrogen.	Phosphoric Oxide (P_2O_5) sol. in conc. HCl.	Phosphoric Oxide (P_2O_5) sol. in 1% citric. ac.	Potash (K_2O) sol. in conc. HCl.	Potash (K_2O) sol. in 1% citric. ac.	pH.
		%	%	%	%	%	%	
A2065 ...	0–2½	4·14	0·190	0·026	0·0013	0·075	0·019	6·50
A2066 ...	2½–14	0·32	0·017	0·014	0·0008	0·039	0·0057	6·76
A2067 ...	14–18	0·19	0·018	0·011	0·0008	0·171	0·0044	7·09
A2068 ...	0–2½	2·78	0·122	0·019	0·0033	0·079	0·0216	6·50
A2069 ...	2½–6	0·38	0·014	0·008	0·0008	0·033	0·0068	6·64
A2070 ...	6–10	0·34	0·014	0·015	0·0010	0·098	0·0043	6·03
A2071 ...	0–2½	0·99	0·062	0·038	0·0194	0·105	0·0131	6·14
A2072 ...	2½–5½	0·29	0·011	0·014	0·0020	0·072	0·0039	6·54
A2073 ...	5½–9½	0·19	0·022	0·005	0·0008	0·184	0·0064	6·84
A2074 ...	0–2	2·98	0·196	0·045	0·0041	0·222	0·0202	6·60
A2075 ...	2–4	0·70	0·043	0·020	0·0006	0·176	0·0109	7·19
A2076 ...	4–8	0·47	0·031	0·014	0·0010	0·206	0·0069	7·02

5.—IRWIN REGION: 7,950,000 ACRES.

The red brown earth zone north of Moora exhibits a number of distinct ecological and soil characteristics. As compared with other regions of the zone, the soils generally are browner, and grey types are far less extensive. Calcium carbonate accumulation in the deeper subsoil, while not general, is far more common than in the Avon region. Wandoo is a less general

feature of the timber and the flat topped mesas are uncommon, except in the confines of the Geraldton area where flat topped ranges of Jurassic age are prominent land marks. Sand heath formations are common and extensive—for instance, the sand heath on the Jurassic plateau west of the Midland Railway stretches with few breaks from Moora to north of the Geraldton-Mullewa line. In the vicinity of Mingenew is an occurrence of blue bush steppe on heavy grey clay soils forming on Jurassic shales. The north-eastern portion of the region is characterised by loose sand heaths and strips of reddish soils forming on sedimentary rocks. These soils are particularly liable to damage by wind action unless properly managed under cultivation.

Generally, however, the zonal soil characters are similar to those of the Avon region and York gum and jam woodlands are the most typical associations. Salmon gum woodlands occur in several districts, for example, Moora, Carnamah and Three Springs, and are associated with strong agricultural soils which are generally calcareous in the deeper subsoil.

The reactions of representative soils of the Irwin region are indicated in Table 5. Both surface and subsoil samples are generally slightly alkaline to alkaline in reaction.

Apart from the areas of poor sandy and gravelly country which are associated with laterite and quartzitic rocks, the soils of the Irwin region are among the most productive in the State. The region is excellent stock country and highly productive of cereal crops. Improved pastures are increasing and in the coastal areas lupins have proved very valuable for stock purposes. Before the advent of superphosphate, the fertile brown soils of the Irwin and Greenough River valleys in the vicinity of Dongara and Geraldton respectively were popularly described as the granaries of the State. These soils are still valuable agriculturally but, in common with other soils of the region less favourably supplied with available phosphate, are now generally responsive to superphosphate.

6.—AVON REGION: 6,700,000 ACRES.

The Avon region is essentially an area of brown and grey soils carrying York gum and jam woodlands. These may be regarded as normal soils. Areas of brown and greyish soils carrying salmon gum, gimlet and morrel occur in isolated patches throughout the bulk of the region. In the south, in the Gnowangerup district, morrel or poot (*Euc. longicornis*) is very common on the better red-brown earth soils and grows in association with York gum and wandoo.

On the sandy heath country, which occurs in restricted areas throughout the region, the soil is a greyish sand with a yellowish subsoil, often with laterite gravel. Wandoo occurs generally throughout the region but more particularly on the grey sandy and gravelly soils and on the light grey gritty soils with a yellowish or a white pipeclay subsoil. The lateritic gravelly soils of the breakaways are of low value agriculturally but carry important mallet (*Euc. astringens*) thickets.

Associated with these gravelly soils of the mallet slopes are frequently found powdery, gravelly soils, generally greyish in colour. In the virgin state they carry morrel (*Euc. longicornis*), mallet, wandoo, etc., and are generally acidic in reaction (pH. 4.4 to pH 6.5). These soils frequently fail to support the growth of cereals unless 14 to 28 pounds of manganese sulphate

TABLE 5.

Distribution table showing the reactions of Soil samples from sites in the Irwin Region which show little or no influence of laterite.

——	Number of Samples in each Range.												Total Number of Samples.
Range, pH	below 4·8	4·8–5·2	5·2–5·6	5·6–6·0	6·0–6·4	6·4–6·8	6·8–7·2	7·2–7·6	7·6–8·0	8·0–8·4	8·4–8·8	above 8·8	
Surface (A horizon)	...	...	...	...	1	7	6	14	9	4	4	...	45
Subsoil (B and B–C horizons) ...	...	...	...	3	5	3	10	13	28	14	14	3	93

Table includes serial Nos. A (32–45, 50–53, 71–87, 147–175, 206–209, 313–332, 2207–2213, 2226–2236, 2243–2247, 2251–2255) and various samples from Indarra.

per acre is applied with the superphosphate. Wild (1934) has described work on these soils and Adams (1937) indicates that peas are less susceptible to the manganese deficiency than are the cereals.

The following distribution table (Table 6) shows the reaction of surface and subsoils from sites showing little or no influence of laterite. It is to be noticed that the surface soils are generally in the range of pH 6.4 to pH 7.6, but the subsoils are typically more alkaline, generally falling in the range pH 8.0 to 9.0. These subsoils are typically non-calcareous in Western Australia but the clays must be base saturated according to the usual standards.

The soils more or less influenced by lateritic formations are generally more acidic.

The Avon region is noted for its stock and cereal production. A large number of high-class Merino studs are located in the region; some of the highest wheat yields of the State have been recorded; and cereal hay is an important industry in some centres. Dairying and pig raising are important adjuncts in many districts, subterranean clover and burr trefoil (*Medicago denticulata*) are important leguminous pasture plants and *Phalaris tuberosa*, Wimmera rye grass, *Bromus* spp., etc., supplement the native grasses.

7.—STIRLING REGION: 2,800,000 ACRES.

South and east of the Avon region is a belt of country in which a proportion of the soils are affected by certain little known geological influences. These have given rise to grey, sometimes grey-brown, types of clayey soils which carry dense thickets of stunted eucalypt known as moort (*Eucalyptus platypus*). In the field, the soils appear to be solonised and may be either acidic or alkaline in reaction. Only one site in every four examined by the writer showed calcium carbonate in the subsoil. Furthermore, it was observed that the deeper layers of the subsoil were more acidic than the upper layers. Associated with these soils are the more typical red-brown earths, and extensive areas of light, sandy mallee country and sand heaths the soils of which are more or less acidic in reaction and of low inherent fertility.

The reactions of soil samples taken to represent the so-called moort country of this region are given in Table 7, and in Table 8 are given the chemical analyses of soil samples collected in 1918 by Dr. G. L. Sutton to represent this type of country.

When first developed for wheat growing about 1917, yields generally were most disappointing and investigations failed to determine the cause. The chemical work reported indicated no abnormalities. This led to the use of these lands for stock raising and the treatment has been effective in greatly improving the soil conditions for the growth of wheat. Wheat growing on these lands is now being successfully practised in many instances. The climate is good and with the use of superphosphate, perhaps such ameliorants as gypsum which are useful for solonised soils, and the establishment of pastures such as wimmera rye grass the region should become an important mixed farming area of the State.

8.—EYRE REGION: 5,410,000 ACRES.

Along the south coast, eastward from the Albany district, is a strip of sand heath country 20 to 30 miles wide and broken only by a number of river valleys which drain the hinterland and flow after the heavier rains.

TABLE 6.

Distribution table showing the reactions of Soil samples from sites in the Avon Region which show little or no influence of laterite.

—	Number of Samples in each range.												Total Number of Samples.
Range, pH	below 4·8	4·8–5·2	5·2–5·6	5·6–6·0	6·0–6·4	6·4–6·8	6·8–7·2	7·2–7·6	7·6–8·0	8·0–8·4	8·4–8·8	above 8·8	
Surface (A horizon)	...	1	...	7	9	15	14	11	6	5	2	...	70
Subsoil (B and B–C horizons) ...	2	1	5	5	4	8	11	4	14	41	37	14	146

(Table includes serial Nos. A (1, 5, 6, 9–14, 16–18, 243–7, 346–381, 384–387, 397–401, 2182–2185, 2323–2327) and samples from the Beegenup soil investigation (eliminating surface crusts and samples below 4 feet).)

TABLE 7.

Distribution Table showing the reactions of Soil samples from sites in moort (Euc. platypus) country in the Stirling region and adjoining portions of the Avon region.

—	Number of Samples in each reaction range.												Total Number of Samples.
Reaction Range, pH	below 4·8	4·8–5·2	5·2–5·6	5·6–6·0	6·0–6·4	6·4–6·8	6·8–7·2	7·2–7·6	7·6–8·0	8·0–8·4	8·4–8·8	above 8·8	
Surface ...	...	...	...	1	3	1	3	2	1	1	...	...	12
Subsoil ...	2	2	3	1	1	4	...	2	7	5	2	4	33

Serial numbers considered: A384–396, 402–430, 435–437.

TABLE 8.

Analyses of Samples of Soil from Moort (Euc. platypus) Country in the Stirling Region. (Samples collected by Mr. G. L. Sutton during 1918 and analysed in the Government Chemical Laboratory—See File 238/17).

Sample.	Colour.	Depth.		Nitrogen.		Phosphoric Oxide.		Potash.		Lime (CaO).		CO_2.		NaCl.	
		Surface.	Subsoil.	Surface.	Subsoil.	Surface.	Subsoil.	Surface.	Subsoil.	Surface.	Subsoil.	Surface.	Subsoil.	Surface.	Subsoil.
		inches.	inches.	%	%	%	%	%	%	%	%	%	%	%	%
1	Grey ...	0—4	4—8	·28	·084	·04	·015	·052	·102	·64	·154	·146	·070	·005	·010
2	Red ...	0—9	9—18	·095	·073	·021	·011	·245	·259	·101	15·46	1·10	14·65	·0033	·059
3	Grey ...	0—3	3—18	·157	·063	·030	·019	·075	·066	·48	·087	·43	·14	·0033	·030
4	Grey ...	0—9	9—18	·095	·028	·018	·012	·35	·28	1·00	4·18	·73	8·19	·033	·15
5	Grey ...	0—9	9—18	·084	·05	·023	·026	·34	·125	·168	·21	·23	·58	·030	·069
6	Grey ...	0—7	7—18	·112	·084	·026	·020	·32	·572	·34	1·09	·040	2·99	·013	·036
7	... ...	0—6	6—18	·095	·078	·041	·019	·100	·049	·067	·059	...	...	·180	·020
15	... ...	0—9	9—18	·067	·042	·020	·022	·039	·042	·129	·022	...	...	·0066	·0099
25	... ...	0—9	9—18	·078	·048	·021	·014	·061	·093	·218	·168	...	...	·0066	·0066
35	... ...	0—9	9—18	·067	·034	·017	·013	·015	·060	·137	·033	...	...	·0099	·0099
45	... ...	0—9	9—18	·129	·053	·027	·011	·088	·115	·478	·078	...	...	·039	·013
12	Grey ...	...	...	·056	·017	·04	·036	·472	·51	·130	·571	·55	·96	·125	·175
13	Brown	...	...	·034	·017	·038	·028	·486	·51	·197	6·94	1·04	7·90	·010	·013
14	... ...	...	...	·034	·028	·016	·011	·18	·26	·15	5·12	·46	6·48	·005	·013
15	... ...	...	...	·095	...	·041	...	·100	...	·067	...	·068	...	·180	...
16	... ...	...	...	·078	...	·049	...	·049	...	·059	...	·072	...	·020	...

This country is of the laterite type and the typical profile is a grey sand of variable depth on a yellowish subsoil. The subsoil may be sandy or a yellow clay or gravelly clay. A description of two profiles from the Esperance District has been given by Teakle and Southern (1936). It is shown that these soils are generally low in plant foods, the clay has a very low base saturation capacity (15 to 20 milliequivalents per 100 gm clay), and the silica:sesquioxide ratio is low (1.42).

Information given in this paper and the results of analyses of samples from 19 other sites on the Esperance plain show the soils to be acidic—generally in the pH 5 to 6 range in the surface and somewhat less acidic in the subsoil. The situation is illustrated in Table 9.

TABLE 9.

Distribution Table showing the Reactions of Soils of the Eyre Region.

——	Number of Samples in each Range.					
Reaction range, pH.	4·8–5·2.	5·2–5·6.	5·6–6·0.	6·0–6·4.	6·4–6·8.	Total.
Surface ...	2	12	3	3	1	21
Subsoil ...	1	...	4	6	2	13

Numerous small swamps occur in the depressions and generally carry a dense tree formation principally of paper bark (*Melaleuca pubescens*) and shrubs.

The "normal" zonal soils occur along the valleys where the country rock has been exposed. From descriptions received these are of the red-brown earth type and are generally the basis of the scanty agricultural or pastoral development of the region.

The coastal fringe is granitic, and calcareous sands blown inland for a few miles form a series of sandhills and aeolian limestones, usually fixed by a littoral vegetation association, with intervening swamps and lakes.

The region is as yet practically undeveloped. However, the rainfall is generally adequate and well distributed and the soil types with a clayey subsoil or a somewhat loamy texture promise to be useful for pasture production. With adequate fertilisation it is possible to grow pastures of rye grass and clovers, and such crops as lupins and Tangier peas. With the development of the stock industry in the heavy textured country to the north, it is likely that this land will be a valuable complementary area in which summer feed and adequate water supplies are available.

C.—ZONE OF GREY AND BROWN CALCAREOUS, SOLONISED SOILS OF THE LOW RAINFALL EUCALYPTUS WOODLANDS—73,100,000 ACRES.

In the Eastern States the grey and brown calcareous, solonised soils typically carry a vegetation of stunted eucalypts popularly known as "mallee." The term mallee indicates a habit of growth of certain eucalypts: a habit of growth consisting of a number of stems, generally less than 4 inches in diameter, arising from an expanded crown or mallee "root." The plants are generally stunted but may reach 30 to 40 feet in height in the

case of the so-called giant mallees. Some species of eucalypts are typically of this habit and some other species exhibit both mallee and tree forms. For instance, *Eucalyptus oleosa*, *Euc. dumosa* and *Euc. gracilis* are typically mallees in the Eastern States but in Western Australia both forms are common and important in ecological associations.

Prescott (1931) recognised the soils of the mallee associations in the Eastern States as forming a new world group and proposed the name "mallee" soils for it. While the mallee soils of the Eastern States are normally associated with mallee vegetation associations, in Western Australia the typical "mallee" soils are associated with a sclerophyll eucalyptus woodland comprising chiefly such trees as salmon gum (*Eucalyptus salmonophloia*), gimlet (*Euc. salubris*), morrels (*Euc. longicornis* and *Euc. melanoxylon*), ribbon bark (*Euc. dumosa*), redwood (*Euc. oleosa* var. *transcontinentalis*), etc. The soils carrying mallee associations in Western Australia are generally of inferior quality as compared with the woodland soils, and intermediate between the sand heaths and the woodlands. In fact, in some districts the soil and vegetation associations constitute a catena comprised of a sequence consisting of soils of salt lake or salina flats, of valley woodland associations, of mallee associations on the slopes, and of sand and gravel heaths on the highlands. To Western Australians, therefore, the term "mallee" has no such general significance as in the Eastern States and a descriptive term is proposed as more appropriate for the zone in Australia than the concise term used by Prescott.

Furthermore, in Western Australia, normal soils of this zone are not generally related to sandhill formations, and Tertiary deposits are known to occur only in certain of the south-eastern areas—for example, the Fitzgerald region. The most prevalent surface geological strata are probably Precambrian sediments of the Whitestone series type (Forman, 1937), outcropping granitic rocks, and ancient valley deposits. The soils on these geological materials are generally very stable and show far less evidence of wind erosion. The sand grains in the mallee and woodland soils of most of the area are sharp and angular and offer greater resistance to wind action than the rounded grains of the soils on Tertiary sediments, as in the Salmon Gums district. For this reason it is probable that the soils of this zone in Western Australia are generally less disturbed than in the Eastern States and exhibit more faithfully the influence of the climatic, geological and biotic factors on the course of soil formation.

Again, in Western Australia there is no distinct "grey and brown soil" zone associated with a savannah association as described by Prescott (1931, p. 67) for the lower rainfall areas of the Eastern States and the north of Western Australia. Heavy textured grey and brown soils do occur in the so-called "mallee" zone of Western Australia. They typically carry a gimlet (*Eucalyptus salubris*) woodland, and typically show crabhole structures; the subsoil is calcareous, the clay is a magnesium-sodium complex and frequently shows slight gypsum accumulation. As these soils are inseparable except as soil types from the other soils of this zone in Western Australia, they are regarded as being of the same zonal soil group. Consequently the zone may be very appropriately designated "grey and brown calcareous, solonised soils."

Some of the soil types of this zone, more particularly the greyer soil types with a light textured surface and a clay subsoil, closely resemble certain solonetz soils described by American workers. The solonetz soil is

typically an intrazonal type and usually occurs as "slick" spots or small areas 4 to 15 feet across with the surface 6 to 15 inches below the general ground level (Kellogg, 1934). General occurrences of soil series with similar solonetz profiles are reported from California, but Nikiforoff (1937) considers these to be primarily the result of geological stratification and not pedogenic processes. It may be asked whether certain of the solonetz soils of Western Australia are not also the result of geological stratification. In the opinion of the writer there is little evidence to support this application of Nikiforoff's hypothesis.

It is thought that the Australian solonised soils, which assume zonal proportions, are the product of pedogenic processes. They form on a variety of geological horizons—Precambrian igneous and metamorphic materials, Tertiary marine and lacustrine deposits, alluvials, etc.—and appear to be the result of climatic and biotic factors. The eucalyptus woodland is the typical plant association and the soils form under a light rainfall, of low leaching powers, which annually deposits 15 to 30 pounds of salt per acre as cyclic salt (Prescott (1931), Teakle (1937)). The profile characters show no evidence of stratification except that to be expected from pedogenic forces.

In common with other zones of the south-western portion of the State, a very considerable proportion of the zone, except in the Zanthus region, consists of heath and scrub soils largely of lateritic origin. These soils are sandy or gravelly in nature, acidic in reaction and low in plant foods and generally occupy the higher levels of the country. The main formations appear to range from 100 to 500 feet above the valley floors. On these higher levels, where the sands and gravels do not occur, or have been eroded, eucalyptus woodlands and mallee associations appear. The soils are closely related to the valley types but the vegetation associations often include red-wood (*Eucalyptus oleosa* var. *transcontinentalis*) as an important tree.

The rainfall of this zone ranges from 10 inches to 15 inches per annum and the Meyer ratio from 25 to 65. Approximately 70 per cent. of the total rain falls in the May-October season. Temperatures are mild in the winter and hot in the summer.

The influence of the rainfall is quite apparent as one proceeds from the higher to lower rainfall parts of the zone. The higher rainfall soils are characteristically greyer in colour and the sandy surfaced types exhibit more or less typical solonetz structure. An extreme example of this structure observed in the Scaddan district has recently been described by Burvill and Teakle (1938). As the average annual rainfall drops below 13 to 14 inches the soils become browner and are typically of a red brown colour.

Over one million acres of country in this zone have been mapped according to standard soil survey methods and some 34 soil series recognised. The chemical work has not yet been completed but is sufficiently advanced to have established the following general characteristics.

This work shows that the following profiles may be regarded as representative of the zone:—

(a) Brown to red brown neutral sandy loam to sandy clay loam resting on a brown to red brown calcareous and alkaline sandy clay subsoil—salmon gum and gimlet woodlands.

(b) Grey to grey brown sand with a bleached subsurface (A_2 horizon), resting abruptly on a grey to olive brown calcareous and alkaline

sandy clay subsoil—salmon gum and redwood woodlands, mallee associations.

(c) Grey to brown powdery, calcareous sandy loams and loams on a fawn to red brown calcareous and alkaline subsoil—morrel woodland.

(d) Grey clay loams on calcareous and alkaline grey clay subsoils—certain gimlet woodlands.

(e) Red brown sandy loams with siliceous hardpan impregnated with calcium carbonate in the subsoil—york gum woodlands of the northern portions.

(f) Brown and red brown non-calcareous sands and sandy loams of the granitic outcrops—jam (*Acacia acuminata*) and york gum mallee (*Eucalyptus foecunda*) associations.

(g) Grey on yellow sands; grey and yellow sand with a yellowish gravelly clayey subsoil; greyish and yellowish gravelly sands and gravels—heath and wodjil (*Acacia* spp.) associations.

The mallee and woodland soils are typically calcareous and alkaline in the subsoil, are generally rich in potash and extremely low in phosphate. The replaceable bases of the A horizon are of the calcium type but in the subsoil magnesium and sodium comprise about 70 to 80 per cent. of the total replaceable bases. Magnesium usually predominates but sodium is always high and sometimes exceeds the magnesium fraction. Organic matter and nitrogen are typically low and are highest in the morrel woodland types. Teakle and Burvill (1930 a and b) have shown that the nitrate-nitrogen status of the cultivated salmon gum and gimlet woodland soils as represented by the Merredin Agricultural Research Station is quite high.

The woodland and mallee soils are generally slightly saline in the subsoil. In the virgin state, in the agricultural areas, the second foot would be expected to contain 0.15 to 0.25 per cent. salt (sodium chloride) and a somewhat higher concentration would be found at lower depths. In the more arid portions of the zone and in the Fitzgerald region the concentration of salt in the subsoil is higher and will generally range from 0.25 to 0.50 per cent.

A feature of particular pedological interest is a strongly acidic layer which is commonly encountered at a depth of 6 to 10 feet. The calcareous subsoil ends more or less abruptly and gives way to this red and grey mottied stiff, sandy clay which generally ranges in reaction from pH 4 to pH 5. Occurrences have been observed in the Lake Brown and Lake King areas and the horizon appears to be general in the Salmon Gums district. Mention has already been made of this horizon in the Scaddan series by Burvill and Teakle (1938). Mineralogical examination of the fine sand fraction of this profile by Dr. Carroll showed the clay minerals to be essentially the same in the calcareous subsoil and in the acid clay horizon. Chemical analyses of this and other profiles of the Salmon Gums district show the silica : sesquioxide ratios of these layers to be similar. Furthermore, the coarse sand : fine sand ratios generally show no major changes between the different horizons. The replaceable base fraction is particularly interesting in that it is practically devoid of calcium but contains a preponderance of magnesium and sodium which together total about 90 per cent. of the fraction. The total replaceable base fraction in this layer amounts to about 30 milliequivalents per 100 grams of clay as compared with about 70 milliequivalents in the B horizon. Pertinent information is given in Table 10.

TABLE 10.

Replaceable Bases of Representative Soils in the Grey and Brown Calcareous, Solonised Soil Zone.

Serial No.	Soil Type.	Locality.	Depth.	pH.	Clay per cent.	Total Replaceable bases m. eq. per 100 gm. soil.	Percentage of Total Bases.			
							Ca.	Mg.	K.	Na.
			inches.							
A598	Wallambin sand	Wilgoyne	17–31	8·3	45·7	19·78	30	36	7	27
A608	Welbungin clay	Wilgoyne	1–6	8·2	49·4	27·55	37	40	4	19
A610*	... ...	... ...	15–37	8·1	44·6	22·53	22	45	2	31
A771/2 ...	Kumarl clay	Kumarl	0–5½	7·9	43·7	30·23	50	33	5	12
A774	... ...	... ...	13–24	7·8	45·9	26·58	24	40	7	29
A777	... ...	... ...	59–105	3·5	59·9	20·20	*nil*	50	7	43
A791/2 ...	Beete calcareous sandy loam	Kumarl	0–8½	7·9	23·4	24·38	44	34	8	14
A794	... ...	... ...	14–32	8·2	29·7	17·67	10	37	15	38
A799	... ...	... ...	96–114	4·0	49·0	16·04	*nil*	43	11	46
A781	Circle Valley sand	Kumarl	14–30	7·9	29·5	17·56	16	40	6	38
A787	... ...	... ...	96–114	5·7	26·6	8·30	*nil*	51	7	42
A499	Milarup powdery, calcareous loam	Lake Kathleen	0–9	8·2	20·9	31·3	34	30	15	21
A502	... ...	... ...	22–41	8·6	35·3	16·91	11	27	22	40
A466	Pallarup sand	Lake King	0–6	7·6	5·0	7·21	42	40	6	12
A468	... ...	... ...	14–27	8·2	39·3	22·25	15	34	16	35
A186	Merredin loam	Merredin Research Station	0–4	6·7	20·8	13·13	43	46	6	5
A189	... ...	... ...	18–28	8·6	48·8	23·58	25	43	6	26

* Gypsum present.

The association of certain eucalypts, for example, *Eucalyptus oleosa, Euc. longicornis, Euc. melanoxylon, Euc. gracilis, Euc. Flocktoniae* and *Euc. conglobata*, etc., with surface accumulation of calcium carbonate is suggestive of the power of certain vegetation associations in the gathering and concentration of soil constituents in the surface layers. As there appears to be no evidence of geological layering and the clays appear to be essentially the same throughout the profile it is postulated that the vegetation is responsible for the removal of calcium from and acidification of this deep horizon. The calcium absorbed would be deposited on the surface with fallen leaves, bark, etc., and on the death of the trees. Under the light rainfall conditions the calcium would accumulate in the B horizon as calcium carbonate. A similar effect of vegetation on the building up of soils in certain constituents, particularly lime and nitrogen, has been observed by Alway and his co-workers (1933 a, b, c) in Minnesota. The broad leafed trees, maple and bass-wood, were found to produce a forest floor layer almost 5 times as rich in lime and up to twice as rich in nitrogen as did jack pine and Norway pine. In New Zealand workers have observed a similar difference in effect between various vegetation associations.

On the basis of the predominance of grey or brown soil colours, the geology, topography, vegetation, prevailing soil types, and the occurrence of special soil features such as hardpan, this zone in Western Australia has been subdivided into 7 regions. Further subdivision is undoubtedly desirable and possible but is regarded as a problem requiring much greater detail than is possible in the present paper.

9.—CORRIGIN REGION: 5,400,000 ACRES.

The region lying immediately east of the Avon region of the red brown earth zone is called the Corrigin region. The average annual rainfall generally will fall into the 14 to 15 inch range. The main vegetation associations, which are present in any part of the region, include salmon gum, gimlet, morrel woodlands, mallee associations and sandy and gravelly heath. In addition, on the grey dune and related soils of the lake systems of the south—Lake Grace, Newdegate, Pingrup—a blackbutt (*Eucalyptus Kondininensis*), boree (*Melaleuca pauperiflora* and *M. quadrifaria*) association is characteristic.

The area is mapped as granitic but most of the parent materials of importance with respect to the principal agricultural soils are of the valley filling type, and possibly ancient sedimentary rocks.

The woodland and mallee soils are typically of greyish colour and form typically on the broad, flat valleys. Grey gimlet soils have long been recognised by farmers in the region and are representative of the heavier soil types. The sandy surfaced soils, with a clay subsoil within less than a foot of the surface, typically show evidence of solonetz structure and in many respects resemble solonetz soils described in other parts of Australia and of the world. Burvill and Teakle (1938) have recently discussed these soils more fully than is possible here.

In common with all other regions of this zone, lateritic sand and gravel heath country is typical of the higher levels. Much of this land has a clayey subsoil and resembles the soils described on the Esperance Plain (Teakle and Southern, 1936), and those observed on the Wongan Hills Research Station. Such soil types are proving valuable agricultural land in many

districts in the region when cropped at four or five year intervals. A judicious fodder and pasture establishment programme and stock raising are essential for the improvement of the soil fertility.

The Corrigin region is one of the most productive of the zone. The soils are less leached than further west and, in addition, the rainfall is more generous than further east. Cereals and sheep are the principal lines of production and improved pastures promise to stabilise the stocking programme. Dairying and pig raising are important adjuncts. The provision of more adequate water supplies, liberal use of superphosphate and better adapted pasture species will greatly increase the agricultural production of the area.

10.—MERREDIN REGION: 7,900,000 ACRES.

The central and eastern portions of the wheat belt of Western Australia are practically delineated by the Merredin region, which is typically an area of brown and red brown woodland soils, with intermediate patches of mallee country, and a considerable proportion of sandy and gravelly soils carrying heath and wodjil (*Acacia* spp.) plant associations. This region may be regarded as the most representative of the grey and brown calcareous, solonised soil zone and further description would be largely a repetition of information already discussed for the zone in general.

Of interest, and perhaps pedological significance, are siliceous hardpan soils which have formed on the extensive flats slightly above lake level in the Lake Brown valleys. These flats typically carry an acacia scrub, saltbush (*Atriplex, Rhagodia*), *Eremophila* spp., *Lycium australe,* etc., with scattered clumps of gimlet and yorrell (*Eucalyptus gracilis*). The soil profile is a red brown sand to sandy loam with a laminated, siliceous hardpan at a depth of about one foot. At one site, this hardpan layer was about one foot thick and was underlain by brownish red, acidic clay of high salinity.

It is worthy of note that the region falls naturally into at least two sub-regions. The northern arm along the Wongan Hills-Mullewa railway line is distinct topographically. It is more undulating and many of the hill formations are timbered by the typical eucalyptus woodlands, while the light sandy and gravelly heath and wodjil soils are commonly in the valleys. In the rest of the region the principal topographic features are the broad, flat valleys and the sandy and gravelly rises. In the valleys are the typical woodland soils and on the rises are the heath and wodjil associations which may be broken by patches of woodland and mallee where the sands and gravels have been removed.

The area is particularly important for cereal production and stock raising which is being facilitated by the provision of water from the Goldfields and local water schemes. The rainfall is low and somewhat uncertain in the north-eastern portion of the region, which is now being reorganised on a basis of stock production, but generally the rainfall is adequate in quantity and incidence for satisfactory wheat growing and stock raising.

11.—FITZGERALD REGION: 11,900,000 ACRES.

The Fitzgerald region occupies the southern portion of the zone and in common with the Corrigin region exhibits a considerable proportion of the greyer soil types. In the western portion of the region sand heath formations appear to occupy a larger proportion of the country than in any other

region of the zone. However, east of the Fitzgerald Peaks, gravelly and related soils are very much less extensive and clayey soils or sandy surfaced soils with clayey subsoils predominate.

Geologically, certain distinctive horizons have been observed, but, in many instances, the explanation is at present obscure. The presence of spicular sandstones probably of Miocene age has been established. A fragmental breccia or conglomerate is common in parts of the Salmon Gums area as a surface formation or has been found in the course of dam construction. Throughout the area a very tough and refractory siliceous rock, sometimes called siliceous "laterite," is very common.

The basal rocks appear to be granitic as in the bulk of the southern portion of the State. Low outcrops occur commonly throughout the region, and Peak Charles, about 20 miles west of Salmon Gums, is a bare granite boss rising to a height of 2,100 feet above sea level and 1,200 feet above the surrounding eucalyptus woodland. This peak rises 700 to 800 feet above the level of present lateritic horizons and probably represents a residual of an erosion cycle earlier than that culminating in the Great Plateau of Western Australia.

Basic dykes and segregations occur and in some districts metalliferous outcrops are the basis of mining activity: Ravensthorpe, Hatter Hill.

Another feature of the landscape is the salt lake, or salina, systems, which are very extensive west of the Fitzgerald Peaks and east of Salmon Gums.

Associated with the proximity to the Southern Ocean is a greater salt concentration in the heavier textured subsoils.

In addition to the ubiquitous salmon gum, gimlet and morrel woodlands and the heaths, certain special associations occur in this region. Probably the most important of these are the white barked redwood (*Eucalyptus oleosa* var. *transcontinentalis*), ribbon bark (*Euc. dumosa*) and merrit (*Euc. Flocktoniae*) woodlands and the considerable areas of stunted eucalypts and mallees such as *Euc. diptera*, *Euc. eremophila*, *Euc. annulata*, *Euc. Dielsii*, *Euc. spathulata*, *Euc. calycogona*, etc.

In many respects the soils resemble those of the Corrigin region but there are larger areas of the browner soil types particularly in the drier parts of the region. Perhaps the most characteristic soil type, however, is a grey to grey brown sand, often bleached in the subsurface layer, resting on a grey to olive brown calcareous, sandy clay subsoil which typically shows some development of solonetz structure. Examination of the woodland soils of the region shows them to be rich in potash, extremely poor in phosphate and to contain an undesirable quantity of salt. The effect of removing the timber on the movement of salt in this region has been discussed by Teakle and Burvill (1938) who show that the salt is rapidly leached from sandy surfaced soils after clearing.

The Fitzgerald region forms part of the undeveloped agricultural areas of the State. Development involves certain difficulties among which are the high proportion of sandy and gravelly heath country and the incidence of soil salinity. With the progress of agriculture in the State, this region will undoubtedly be utilised for cereal production and, more particularly, stock raising, but the areas of good woodland soils are too scattered for convenient land settlement.

12.—COOLGARDIE REGION: 23,000,000 ACRES.

The Coolgardie region lies immediately east of the agricultural areas and receives an annual rainfall averaging 10 to 11 inches.

The soil profile is characteristically of the solonised type with a calcareous subsoil but, under the low rainfall conditions, is less developed than in the more western regions. The surface is typically a red brown to brownish red sandy loam, sometimes a sandy clay loam, neutral to slightly alkaline in reaction, resting on a more or less massive sandy clay loam to sandy clay subsoil which contains several per cent. of calcium carbonate. Some concentration of salt is observed, particularly in the heavier soil types, and salinas often occupy the lowest portions of the valleys and depressions. Insufficient information is available for remarks concerning other chemical properties such as nitrogen, phosphate, potash, replaceable bases, etc.

ERRATA.

P. 157, line 15: For "*larvas*" read *lavas*.

P. 161, line 16: For "*Hakes*" read *Hakea*.

P. 175, line 8: For "*lateriate*" read *laterite*.

campaspe and a number of blackbutts (*Euc. Le Souefii, Euc. Dundasi,* etc.), as well as acacias, *Eremophilas*, saltbushes (*Atriplex* spp.) and sage bush (*Cratystylis conocephala*).

The soils are typically calcareous from a depth of 4 to 6 inches but the grey types, usually associated with morrel timber (*Euc. oleosa and Euc. melanoxylon*) and blackbutts, are calcareous from the surface. Blackish ferruginous gravel is of very common occurrence as a light surface pavement.

(2) Ancient sedimentary formations.

Sedimentary horizons, of which the Whitestone series (Forman, 1937) is a representative, appear to occur between the hill formations and are associated with reddish brown to brownish red soils which exhibit a "flat" surface appearance characteristic of low rainfall soils.

The subsoil is typically calcareous from a depth of 4 to 6 inches.

Gimlet (*Eucalyptus salubris*) is the most characteristic timber but salmon gum (*Euc. salmonophloia*), morrel (*Euc. oleosa*) and redwood (*Euc. oleosa* var. *transcontinentalis*) are important in the association.

The undergrowth consists largely of *Acacia* spp., *Eremophila* spp., saltbush, etc.

(3) Granitic outcrops.

The grantitc outcrops, occurring as low hills and bosses, are generally associated with more immature and stony soils, lighter in texture and browner in colour. Calcareous accumulation in the subsoil is not characteristic except in heavier types. A more stunted vegetation grows on these types. Golden mallee (*Euc. foecunda*), jam (*Acacia acuminata*), kurrajong (*Sterculia Gregorii*), *Eremophila* spp., and some salmon gum (*Euc. salmonophloia*), and gimlet (*Euc. salubris*) are on the better soils and a heath, often largely tamma (*Casuarina campestris*), on the immature and skeletal types. Some grasses and herbs usually grow on these soils, rendering them of some grazing value in the virgin state.

(4) Lateritic and sandy formations.

Particularly on the western portion of the region and to the south large areas of high level heath country are associated with yellowish gravelly and sandy soils.

A wide variety of stunted shrubs and small trees grow on these soils and many produce a colourful display of flowers in the proper season.

Acacias, *Grevilleas, Hakeas, Actinostrobus, Thryptomene,* etc., are among the members of the plant association on these low fertility soils. The formation usually represents residual lateritic horizons, but in some cases other quartzose horizons are the parent material of the soil type which has developed.

Except on the western fringe, the soils of this region are not developed for agriculture on account of the deficient rainfall. Goldmining is the chief industry, but sheep and cattle raising are followed where saltbush and bluebush provide grazing and water supplies may be obtained.

13.—ZANTHUS REGION: 14,500,000 ACRES.

Abount 54 miles east of Kalgoorlie there is an apparent change in the appearance of the country. A somewhat similar change is noticeable at Fraser's Range some 66 miles east of Norseman. These points are taken as the western boundary of the Zanthus region.

In the Zanthus region greenstone intrusions, so characteristic in the Coolgardie region, are rare, and ironstone gravel or lateritic formations appear to be absent. Numerous salt lakes or salinas occur in the eastern part of the region.

The region is gently undulating and considerable portions are characterised by broad saltbush-bluebush-grass plains with scattered mulga and *Pittosporum,* interspersed with belts and patches of eucalyptus woodland and, in some cases, acacia and *Eremophila* scrubs. Kurrajong is fairly common, while spinifex enters the timber associations on the more sandy soils in the eastern part of the region.

In many instances, the timbers grow on the slightly higher country intersecting the plains. Salmon gum, morrel, redwood (*Euc. oleosa* var. *transcontinentalis*), gimlet, york gum mallee (*Euc. foecunda*), *Casuarina* and acacias (probably *A. microneura*) are the chief timbers, and there are three main types of undergrowth: (a) saltbush and bluebush—generally on the heavier and more calcareous soils; (b) acacia scrub, *Eremophila* spp., *Melaleuca* spp. —generally on the redder soil types—often heavy in texture; (c) spinifex—generally on the red sandy soil types. It has been observed that extensive developments of the saltbush-bluebush plains occur in the western part of the region along the Transcontinental railway and around Balladonia and eastwards (McLean, 1926). McLean also observed that sandplain country occurred south of Mt. Ragged which apparently fixes the south-western boundary of the region.

The soils show the principal characteristics of the zone. They range from red-brown and brown to grey in colour and show accumulation of calcium carbonate in the subsoil. Limestone rubble is common and, in the plain country, ridges of limestone are frequent occurrences. A certain amount of

pastoral development has taken place in this region but scanty water supplies are a drawback. Many of the soil types would be suitable for wheat production but the rainfall appears too low for agriculture.

14.—NINGHAN REGION: 7,600,000 ACRES.

The Ninghan region is really transitional between the red and brown acidic soils of the Yalgoo region and the main portion of the grey and brown calcareous, solonised soil zone. It is distinct from other regions in many respects.

The vegetation associations are principally eucalyptus woodlands and heaths but important areas of cypress-pine (*Callitris glauca*) and acacia scrub also occur. Unlike other regions, grasses and herbage grow in certain of the associations, particularly the york gum (*Eucalyptus foecunda* var. *loxophleba*) woodland.

The soils of the region are distinctly redder than in other parts of the zone and many types exhibit a surface "flatness" more characteristic of the red and brown acidic soil zone. Furthermore, a laminated, siliceous hardpan, commonly impregnated with calcium carbonate, is characteristic of the regional woodland, cypress-pine and acacia scrub soils. In addition to the normal salmon gum, gimlet and morrel woodland soil types, and the heath and wodjil soil types, representative profiles include—

(a) Red brown and red sandy loams with a "flat" surface and a laminated siliceous hardpan impregnated with calcium carbonate. These may be regarded as the characteristic woodland soils of the region and carry a woodland of york gum, jam (*Acacia acuminata*) and various scrubs. Grasses and herbage grow in the wet season.

It is interesting that this york gum is classified as the same species and variety (*Eucalyptus foecunda* var. *loxophleba*) as that of the red brown earth zone although its habit of growth is quite distinct.

(b) Salmon brown sandy soils of cypress-pine areas. These exhibit siliceous hardpan development, are acidic in reaction and generally low in plant foods. Simpson and Teakle (1934) have discussed these soils in some detail.

The occurrence of calcium carbonate in the hardpan, particularly as coatings between the laminae, suggests that the eucalyptus woodland association is encroaching on the acacia semi-desert scrub land and, concurrently, calcium carbonate is accumulating in the subsoils, *i.e.*, pedocals are being formed. It may be expected that the siliceous hardpan will slowly disintegrate in the alkaline medium and the profile improve agriculturally.

The agricultural value of the woodland soils of this region is somewhat lower generally than in regions where the hardpan is absent. However, successful cereal production and stock raising is practised throughout.

15.—HARTOGS REGION: 2,800,000 ACRES.

The extreme northern portion of this zone is at present outside the agricultural areas and has been mapped as the Hartogs region. A very considerable area of this region consists of heath often showing the form of sand dunes now fixed by the vegetation. The sand is a yellowish grey in colour in contrast with the red sands of the sand dunes in the Minilya region. Associated

with the sand heaths are areas of brown and red brown soils carrying eucalyptus woodland (principally york gum (*Euc. foecunda* var. *loxophleba*)), cypress-pine, mulga and mallee associations. G. H. Burvill (private communication) states that the mallee country of this region more closely resembles the drier portions of the Eastern States mallee than any other in Western Australia. He has observed that the heavier textured red brown soils of the flats carried stunted york gum, acacia scrub, *Eremophila* spp. while on the intervening red brown sandy rises mallee (including *Euc. oleosa*) and scrub predominated. The subsoils of these types generally appeared to be calcareous and in some portions a limestone pavement was very apparent. In certain areas mulga, cypress-pine and mallee grew on red brown soil types.

D. THE ZONE OF RED AND BROWN ACIDIC SOILS OF THE ACACIA SEMI-DESERT SCRUB—204,000,000 acres.

Between the north and south 10 inch isohyets lies a belt of red and brown soils, generally more or less acidic in reaction, and characterised by an acacia scrub, ranging from 10 to 20 feet in height, which is collectively described as mulga.

The western portion of the zone consists of Cainozoic, Cretaceous and Permian deposits with more or less horizontal bedding. East of these, the rocks are Pre-Cambrian; in the north, the Nullagine and Mosquito Creek Series (mainly sediments, lava flows and some granites) occur, and in the south, granites with small, but important, intrusions of greenstones, predominate.

Physiographically, the area is portion of the Great Plateau, now eroded to broad, flat, featureless valleys on the east and, in the west, to a more dissected and hilly topography. Except in the coastal areas the elevation generally ranges from 1,000 to 2,000 feet above sea level. The residuals of the Great Plateau now appear as low hills, ridges, and quite imposing ranges rising abruptly out of the plain or "new" plateau, and are frequently capped with laterite.

In the eastern portion of the zone spinifex covered sandhill formations occur, particularly on certain sedimentary rocks, and small saltbush and bluebush steppes are important features from the pastoral viewpoint.

The bulk of the area (west of 120° E. lat.) is drained by a number of intermittent streams running into the west coast; the Murchison, Wooramel, Gascoyne and Ashburton being the chief rivers. East of this the drainage is endoreic, i.e., into depressions and "lakes," or salinas, of the interior. The Savory Creek at Mundiwindi and such "lakes" as Lake Carey and Lake Carnegie are examples of this interior drainage system.

The drainage of this low rainfall zone contrasts with that of the more southern zone of grey and brown solonised soils where the rainfall is higher, but the precipitation per wet day is considerably lower, and where no "rivers" ever flow to the sea.

The climate is definitely arid. The rainfall is generally below 10 inches per annum and according to Barkley (1931) the coefficient of variation ranges from 30 to 60 per cent. Evaporation is high and ranges from about 7½ feet in the south to nearly 15 feet per annum at Mundiwindi. In no month of the year does the average rainfall exceed the evaporation. If a monthly precipitation: saturation deficit ratio of 7.5 be taken to indicate the minimum

moisture conditions for continuous plant growth, only in June will the conditions in the bulk of this zone approach or exceed this figure. On the coast, at Carnarvon, this ratio is exceeded during June and July and at Yalgoo, near the boundary of the grey and brown calcareous, solonised soil zone east of Geraldton, during May, June, July and August (Teakle (1936) p. 497). However, much of the useful rain of this zone comes in heavy falls, which are valuable for the xerophytic and ephemeral plants in whatever season of the year they occur.

The vegetation of the zone is predominantly mulga. Botanically, mulga is *Acacia aneura* but the term may conveniently be extended to include a number of associated species of *Acacia*, generally ranging from 10 to 20 feet tall, including bowgada bush (*A. linophylla*), *A. Burkittii*, curara (*A. genistoides*), minerichi (*A. Grasbyi*), snake bush (*A. eremaea*), gidgee (*Acacia* sp.), etc.

A wide variety of shrubs and bushes grow with the acacias. Examples are beefwood (*Hakes* sp.), cork (*H. subera*), turpentine bush (*Eremophila Fraseri*), poplar (*Plectronia latifolia*), flannel bush (*Solanum ellipticum*), poverty bush (*Acacia leptopetala*), starvation bush (*Eremophila Youngii*) and emu bush (*Eremophila longifolia*). Eucalypts and other trees generally fringe the creeks and grow in the river valleys. River gum (*Eucalyptus rostrata*), coolibah (*Euc. microtheca*) and *Casuarina lepidophloia* are commonest representatives. *Eucalyptus longicornis* and desert gum (*Euc. eudesmoides*) are fairly common in certain areas.

With the shrubs and timbers are a wide variety of ephemeral herbs, particularly *Compositeae*, in the southern portion of winter rainfall, and perennial grasses in the northern areas where summer rainfall predominates.

Spinifex occurs in patches and saltbush and bluebush are common, particularly in the east.

The soils fall into two main groups—

(a) Those of the central and southern areas in which a well defined hardpan has developed on the broad plains.

(b) Those of the northern and western portions where the topography is more hilly and the hardpan is absent or only intermittently developed.

In the surface features the soils generally are similar, being shades of red and brown in colour, more or less sandy in texture and non-calcareous. The profile generally shows little differentiation except where the hardpan occurs. The subsoil may be recognised by slight clay accumulation, concentration of pebbles and small stones and a brighter colour. Serir* formation is typical: the commonest stones of the pavement are white quartz and dark red brown quartz-haematite.

Chemically, the soils are not rich in plant foods, are very low in water soluble salts, and calcium and magnesium predominate in the replaceable base fraction. In the hardpan soils the content of replaceable bases is very low, ranging from 10 to 30 m. eq. per 100 gm. of clay and the

*The term "serir" has been adopted in soil nomenclature for those desertic soils which are characterised by a stony surface or "desert pavement." It is of Arab origin. Such formations are commonly called "gibber" plains in Australia.

TABLE 11.

Distribution table showing the reactions of Soil samples from sites in the zone of red and brown acidic soils of the acacia semi-desert scrub.

—	Number of Samples in each Range.										Total Number of Samples.
Range, pH	4·8–5·2	5·2–5·6	5·6–6·0	6·0–6·4	6·4–6·8	6·8–7·2	7·2–7·6	7·6–8·0	8·0–8·4	8·4–8·8	
A.—Sites other than Carnarvon terrace soils.*											
Surface	6	5	1	4	7	5	6	2	6†	5†	47
Subsoil	2	3	1	1	4	5	2	...	1	2	21
B.—Sites from the Carnarvon terrace soils.‡ (Teakle & Southern, 1935.)											
Surface	...	...	...	...	...	...	2	2	7	1	12
Subsoil	...	...	...	...	...	...	2	2	3	4	11

* Includes samples A1193–1217, 1879–1902, 1833–1853, 2549–2567. † Includes one sample from a garden in which the soil has apparently been rendered alkaline by the treatment. ‡ Includes samples A1156–1192.

clay appears to be of the nontronite type. Also, they are typically acidic in reaction with a pH value of 5 to 7. (See Table 11.) More alkaline soils are generally associated with lacustrine formations or patches of calcium carbonate accumulation.

The nature and occurrence of the hardpan has already been discussed (Teakle, 1936). It appears as a laminated subsoil cemented by silica and generally coloured by oxides of iron. The surface soil usually ranges from six inches to 36 inches deep and rests abruptly on this very hard layer commonly known locally as cement. The hardpan occurs as laminae about one inch thick, is generally non-calcareous in the upper layers and may be many feet thick. Calcium carbonate is frequently observed with depth as small lenses between the laminae and sometimes as a surface coating on the otherwise non-calcareous layers. Melville (private communication) has observed calcium carbnate accumulation at a depth of about 10 feet and immediately above the country rock at Boolardy Station. Unconsolidated river deposits are reported to lie below the hardpan in some instances.

The ferruginous colouring may be readily removed by digestion with hydrochloric acid, which leaves a white sandstone. Hydrofluoric acid attacks the siliceous cement and disintegrates the hardpan. Instances have been observed in the field in which the hardpan is whitish and not coloured by iron oxides.

It has been observed in other instances in Western Australia and also by Taylor and England (1929) in the Eastern States that siliceous cementation is liable to occur where occasional floodings take place. As the soils of the hardpan zone are liable to periodic floodings following the occasional very heavy rains, it is thought that this condition, under a slightly acidic reaction, is responsible for the solution of silica which is subsequently deposited as a cement in the subsoil on drying out.

Jutson has explained the formation of the broad, featureless valleys of the hardpan zone as the result of wide lateral erosion with restricted vertical corrasion. In these valleys, drainage of the soils is apparently largely lateral and calcium carbonate moves out in solution to be deposited in "opaline"* patches and in broad lacustrine formations. Where the calcium carbonate is deposited, it is usual to find salt bush and blue bush predominating in the vegetation association.

Where sand formations occur, usually obviously aeolian formations, spinifex is the most characteristic element of the vegetation.

The acacia semi-desert zone is subdivided into regions on the basis of soil, topographic and vegetation features.

Group A.—Regions of Hardpan soils.

16.—MURCHISON REGION: 43,800,000 ACRES.

The Murchison Region presents the most typical occurrence of the red hardpan soils. It is a high level plateau characterised by broad, featureless plains of red serir soils with a hardpan generally within a foot of the surface. The plains are broken by various types of residual hills. It is typically a mulga formation but the mulga is much more sparse than further south. North of the Robinson Range (Peak Hill) perennial grasses are im-

*Patches of calcium carbonate accumulation, usually in the form of white nodules, are designated as "opaline" patches in popular parlance. True opal does not occur but flints have been observed in one instance.

portant pastorally, but to the south, where winter rains predominate, ephemeral herbage constitutes the principal ground vegetation—and then only after rains. This southern area is largely granitic with important outcrops of greenstone. The northern portion is predominantly of the Nullagine and Mosquito Creek series.

Some five groups of soil have been recognised—

(a) Mulga bush plains—brownish red sand to sandy clay loam with the hardpan at 6 to 12 inches deep. The soils are generally gravelly and show the serir surface but areas of stoneless soils may be observed. Where the reddish sand has accumulated in depressions or on low ridges, the hardpan is at a greater depth. These areas are known as wandarrie soils and are most suitable for homestead gardens.

(b) Channel country—heavier textured soils and "opaline," or calcareous patches are associated with the broad river channels. The river channels themselves are brown sands and grits.

The vegetation reflects the wetter conditions and includes curara, wattles, mulga, eucalyptus, *Casuarina lepidophloia*, grasses (*Aristida* spp.), *Eragrostis* spp., and kangaroo grass (*Themeda triandra*). Native vetches (*Swainsona* spp.) and native lucerne (*Trigonella suavissima*) flourish after periods of flooding. The association is a woodland or savannah woodland.

(c) Undulating granitic country where granites are exposed at shallow depths—a brownish red immature soil with decomposing granite in the subsoil and an abundance of granitic boulders and outcrops is observed. The vegetation resembles that of the mulga bush plains.

On Murramunda Station near Mundiwindi a similar formation of brown soils occurs. The typical vegetation associations are mulga and grass, and mulga, grass and spinifex.

(d) Lacustrine formations and calcareous soils—brown, pinkish brown to pinkish red calcareous soils with calcareous rubble in the subsoil occur in relatively small patches throughout the region. Mulga and grasses may grow on these soils but more generally the vegetation includes saltbush and bluebush and sometimes samphire with or without mulga. These areas are very valuable pastorally as the edible vegetation is within reach of the sheep.

(e) Stony and gravelly hill formations carrying (i) mulga bush, (ii) spinifex associations. Laterite frequently occurs on these formations.

17.—YALGOO REGION: 19,100,000 ACRES.

South of the Murchison region, and bordering the grey and brown solonised soils of the eucalyptus woodland the country is more undulating, the granites are exposed more frequently, considerable areas of browner soils are observed, there is evidence of a more general occurrence of laterite in patches, and the vegetation shows many typical features. The elevation is lower and ranges from about 1,000 feet to 1,400 feet above sea level.

Geologically, the area is mapped as predominantly granitic and on the granitic exposures the soil is commonly a red brown, coarse, loamy sand resting on decomposing rock. Laterite is common and lateritic gravelly soils, usually yellow brown in colour, occur where the gravels have been broken in the course of erosion. Some of these gravelly soils exhibit a peculiar physical condition in that the surface sand lacks coherence.

The vegetation is predominantly of the acacia scrub type and some patches of dense, tall, well grown mulga may be observed. However, cypress-pine (*Callitris glauca*) is common and forms a woodland in patches on the western and southern parts of the region. *Eucalyptus oleosa*, as a mallee, is common in patches, york gum (*Euc. foecunda* var., *loxophleba*) occurs in many places and jam (probably *Acacia acuminata*) is to be observed in many of the associations. Kurrajong (*Sterculia Gregorii*) grows more commonly as scattered trees in the inner portions of the region.

The soils of the flat areas, which may be taken to represent the zone, are typically of the serir type, are usually brown, red brown and brownish red in colour, sandy loam in texture and typically show the hardpan at shallow depths. While the hardpan is usually red brown in colour with black markings, outcrops of a brittle, light buff coloured type have been observed. In the hills much stony surfaced country exists. Sandy areas typically carry spinifex and scattered gums.

East of Mt. Magnet, more bluebush (*Kochia*) and salt bush (*Atriplex*) are seen with the mulga, on "opaline" patches, and on patches of open plain. These open bluebush and saltbush flats are often highly calcareous and flints are found in some of the limestone formations.

Running southwards from Paynesville on the Sandstone railway line, is a strip of red crumbly clay country carrying saltbush and bluebush. This strip is 10 to 40 chains wide and reaches the rabbit proof fence about 100 miles south of the railway line. It is probably related to some special geological feature and shows affinities with the brown soil group of the Kimberleys and the Fortescue Sunkland, rather than with the other soils of this region.

The soils of the cypress-pine associations have been described and discussed by Simpson and Teakle (1934). It appears that these soils are generally red brown in colour (usually a salmon tinge is noticeable in the field), loamy sand to sandy loam in texture and acidic in reaction. They are relatively low in the usual plant foods, very low in water soluble salts, and in the lower lying portions show a siliceous hardpan in the second foot layer.

18.—BARLEE REGION: 44,100,000 ACRES.

East of the Yalgoo and Murchison regions, salt lake formations and saltbush flats become very important soil and pastoral features and are associated with spinifex plains and sandhills, and mulga country. It is estimated that each of these three formations occupies approximately the same proportion of the region.

Talbot (1928) has observed that the reddish soils of the sandy plains, carrying spinifex, desert gum and bloodwood, are forming on granitic rocks, while the sandhills form where the rocks are sedimentary. Possibly the shape of the sand grains is an important factor in conditioning this difference in topography under a similar vegetation association. In the north-western portion of the area, he has reported that the Mosquito Creek series is characterised by mulga flats and red soils, while sandhills have formed on rocks of the Nullagine series.

The mulga scrub, often very dense, generally appears to be associated with reddish soils resembling those of the Murchison region. Serir soils are common, red sandy soils are developed extensively under a mulga-spinifex

association, and mulga and saltbush often associate on the richer flats. Hard, red soils, with a cover of mulga, occur on diorite outcrops. Hardpan appears to have developed generally in these "mulga" soils.

In May, 1938, through the courtesy of Miss N. Burbidge, of the University of Western Australia, a number of soil samples were obtained from Glenorn Station, Malcolm. These represented various vegetation associations studied in the field and show that the soils range from brown to red brown in colour and from sands to sandy clays in texture. Certain types are alkaline in reaction and some of these are calcareous but other soils are slightly acidic. Hardpan was present in most types examined at depths ranging from 4 inches to over 4 feet but was generally encountered between 6 and 18 inches deep. Some of the lowlying soils and soils from claypans and lakes were distinctly saline but the "normal" soils were very low in soluble matter. Information available is summarised in Tables 12 and 13.

TABLE 12.

Analyses of Soil Samples from Glenorn Station, Malcolm, Barlee region. Collected May, 1938, by Miss N. Burbidge, University of W.A.

Serial No.	Depth.	pH.*	Lime ($CaCO_3$).	Spec. Resist. ohms at 60° F. (1 : 5 water suspension).	Salt (NaCl).
	inches.				%
2549	0—6	8·50	rich	1,410	0·15
2550	0—6	8·32	nil	730	0·36
2551	0—6	8·47	nil	13,700	0·008
2552	0—6	8·24	present	550	0·36
2553	at 36	8·74	rich	432	0·63
2554	0—6	7·26	nil	29,700	0·005
2555	0—6	6·46**	nil	41,000	0·005
2556	0—6	5·60	nil	15,500	0·003
2557	at 18	6·46	nil	38,700	0·005
2558	0—6	6·50	nil	32,000	0·003
2559	0—6	7·38	nil	238	1·33
2560	0—6	8·27	rich	2,880	0·07
2561	0—6	6·85	nil	500	0·61
2562	0—6	7·32	nil	16,850	0·01
2563	0—6	6·59	nil	730	0·38
2564	0—6	8·54	nil	1,250	0·22
2565	0—6	6·84	nil	22,300	0·008
2566	0—6	8·23	nil	1,190	0·16
2567	0—6	6·31	nil	21,800	0·008

*Quinhydrone electrode—1 : 5 suspension. Rapid positive drift (to higher pH) occurred with most samples. Reading after 10 seconds adopted.

**Glass electrode.

The extensive saltbush and bluebush flats are generally associated with pinkish and brownish calcareous soils and are of considerable importance pastorally as the edible forage is readily available to the stock. In combination with the mulga and spinifex areas a very stable grazing unit is established but is liable to damage by overstocking.

TABLE 13.

Distribution table showing the reaction of surface Soil Samples and the depth of the hardpan at certain sites on Glenorn Station, Malcolm.

——	Number of Samples in each Range.							
Range. pH	5·6—6·0	6·0—6·4	6·4—6·8	6·8—7·2	7·2—7·6	7·6—8·0	8·0—8·4	8·4—8·8
	1	1	3	2	3	....	4*	3*
Range of Depths of Hardpan (inches)	0—6	6—12	12—18	18—24	24—30	30—36	36—48	deeper than 48
	3	31	21	9	14	7	4	7

* Includes one sample from a garden in which the soil has apparently been rendered alkaline by the treatment.

19.—WARBURTON REGION: 57,000,000 ACRES.

The area of transitional country between the zone of typical "mulga" country and the main central sandhill region (the Carnegie region) has been included in the Warburton region. Two main formations characterise this area:

(a) The sandhill and sand plain country carrying a cover of spinifex and desert mallees.

(b) Areas carrying mulga and associated scrubs on flats between the sandhills and on the country associated with the ranges.

Talbot (1928), Talbot and Clarke (1917), and Forman (private communication) have made observations in this area. On their expedition from Laverton via the Townshend Range to the South Australian border, Talbot and Clarke mention the mulga, spinifex and saltbush country in the vicinity of Laverton (Barlee region), but describe the rest of the traverse to the Townshend Range as largely red sandy plains and red sandhills carrying spinifex and desert mallees and gums. The sandhills range from 200 yards to a mile apart and average about 30 feet high. Breakaways and stony rises (probably of the Cretaceous Wilkinson Range series) occur and usually carry a vegetation cover of spinifex probably resembling the Ophthalmia Range in this respect. Red sandy and loamy soils, which become very boggy when wet, are associated with these rises and usually carry mulga, desert gums, etc., with wandarrie and wind grasses (*Aristida* spp.). Forman (private communication) has observed that hardpan is characteristic of the soils of the mulga flats of the region.

In the Warburton Range area is about a million acres of quite good pastoral country of the mulga type. The red soil flats carry mulga and spinifex and the sandy soils mulga, wandarrie and wind grasses. Saltbush occurs on some flats and appears to be prevalent south-west of the range. Mr. Forman has observed that the heaviest mulga is associated with the sediments and volcanics of the Nullagine series and the quartzites carry spinifex and odd fig trees (*Ficus* sp.).

The western portion of the region comprises extensive areas of red sandhills carrying spinifex and also plain country carrying mulga and other scrubs, between the ranges and hills. South of Lake Carnegie are extensive saltbush plains and samphire flats with scattered mulga.

The Warburton region is generally of low pastoral value but patches of good country exist and are being developed for sheep where distances from established centres are not too great. Some of the best grazing land

is in the Warburton Range area is isolated from Laverton by 300 miles of very poor and inhospitable country. Successful and well-known stations occur in the more western sections of the region (for example, Wongawol Station on Lake Carnegie).

The Warburton region of Clarke (1926) is restricted to the range country of the eastern portion of this region.

Group B.—Regions without general development of hardpan.

20.—GASCOYNE REGION: 13,500,000 ACRES.

The region includes the bulk of the Permian deposits east of the Minilya region as well as Nullagine and granitic rocks and is characteristically hilly and very stony. Serir formation is most marked and the soils, generally brown to red brown sandy loams to loams, are deeper and more immature than in the Murchison country further inland. Some cementation in the subsoil is common and the hardpan is observed in some places. Limestones are often associated with heavier textured soils. The only soil examined for this region (A1196) was a soil with exceptionally high content of replaceable bases (230 m. eq. per 100 gm. clay) and peculiar colloidal properties. The fine sand fraction contained beidellite instead of the more common nontronite and the reaction was slightly alkaline.

The general vegetation is similar to other parts of the zone but a larger proportion of perennial grasses in many parts allows a heavier stocking programme to be followed.

Laterite is observed in the region, *e.g.*, at the Wooramel crossing.

21.—MINILYA REGION: 7,400,000 ACRES.

Along the west coast, on sediments ranging from Cretaceous to recent in age, occurs a strip of country much of which is characterised by parallel sandhill formations 10 to 30 feet high, running generally northerly and southerly in direction, and fixed by acacia scrubs such as bowgada bush.

The soil of the sandhills is brownish red sand with no profile development. Between the sandhills are flats of higher fertility which carry mulga, wattle (*Acacia sp.*), *Hakea* spp., with a variety of grasses and herbage following rains. The soil of the flats is a brownish red sandy loam with clay accumulation in the subsoil. Cementation is observed in some instances but is uncommon, probably on account of the immaturity of the soils. A shallow claypan usually occupies the lowest portion of the flat.

Coastal formations include a variety of sandhills carrying shrubs, wattles, halophytes, etc., quite distinct from the more inland types.

Along the rivers recent alluvial soils, of a relatively high fertility level, have been deposited in terraces and, where irrigation is possible, are valuable for tropical agriculture (Teakle & Southern, 1935). In contrast with the normal soils of the zone, these soils are alkaline (Table 11).

The Minilya region corresponds generally to Clarke's (1926) Carnarvon natural region. It joins the spinifex steppe formations on the north, and the yellowish and greyish sand heath formations in the "mallee" zone on the south. Forman (private communication) considers that this break from red to yellowish and greyish sandy soils at the Minilya-Hartogs boundary is probably due to the exposure of a calcareous bed of the Cretaceous series

in the Hartogs region in contrast with argillaceous beds in the Minilya region. The hilly formations to the east are separated and included in the Gascoyne region.

22.—ASHBURTON REGION: 19,100,000 ACRES.

The upper courses of the Ashburton and Fortescue rivers drain the northern portion of the mulga zone and the southern portion of the desert steppe zone of the North-West. The area may be regarded as a dissected plateau averaging 2,500 to 2,750 feet above sea-level. Mt. Bruce (4,024 feet), the highest point in Western Australia, lies in the region. The dissection has resulted in the formation of rough, stony hills and ranges which are covered with spinifex and small trees and shrubs such an kanji (*Acacia pyrifolia*). Between the ranges are valleys, the heavy textured soils of the bottoms of which are of the brown type, similar to the soils of the tropical savannahs, etc., of zone H. Likewise these soils carry a savannah or grassland vegetation association. The lower slopes typically carry a mulga association, but hardpan as a feature of these soils has not been reported.

The region is regarded as transitional between the semi-desert steppe zone to the north and the mulga zone to the south.

The eastern portion of the region includes the Fortescue sunkland represented by the Roy Hill and Ethel Creek Stations. In this portion, the valley and plain soils observed fall into four groups.

(a) Brown clay soils of the Fortescue savannah and other grasslands. The profile is a brown clay loam or clay on a hard clay subsoil. Cracking during dry weather is characteristic. Patches of calcium carbonate accumulation are common and here the soil has a crumbly structure.

Inundation during wet periods and the heavy texture give the soil the equivalent of a higher rainfall. Consequently, the vegetation and soil are more representative of higher rainfall areas such as the Fitzroy of the Kimberleys, and Queensland. A Mitchell grass (*Astrebla pectinata*) savannah is a prominent feature. A variety of other grasses occurs, and the scattered trees include coolibah (*Eucalyptus microtheca*) and sugar gum (*Euc. sp.*).

(b) Reddish brown to brownish red sandy loams to sandy clay loams on a sandy clay subsoil, apparently forming on material of alluvial origin as well as on higher level country. Hardpan was not observed.

The vegetation includes mulga, eucalypts, *Hakea lorea, Cassia notabilis* and spp., as well as grasses and spinifex.

(c) Sandy and serir plains of the valley which carry spinifex and scattered coolibah and river gum. Wind erosion has caused severe damage on some of this country.

(d) Brownish red heavy clays of basaltic plains. Mulga and grass grow on these soils.

Geologically, the region is principally of the Nullagine and Mosquito Creek Series. Laterite commonly occurs as a capping of the hills.

Cattle and sheep are grazed in this region but the difficulties of marketing are promoting a swing towards sheep.

Grasses of the grassland and savannah formations, and associated with the acacia scrub (mulga) are of great importance and a representative variety from Turee Creek Station has been examined seasonally by Beck and Underwood (1938) for chemical properties.

E.—THE ZONE OF BROWN ACIDIC SOILS OF THE SEMI-DESERT STEPPES OF THE NORTH WEST—36,600,000 ACRES.

The northern portion of the north west is characterised by "spinifex" or porcupine grass country (*Triodia* spp., etc.) and may be described as a semi-desert steppe formation. Scattered bushes and small trees grow and the better rainfall areas in the proximity of the coast could probably be described as a semi-desert savannah. Little is known of the soils except that they are generally brown to red brown in colour, sandy to sandy loam in texture, generally non-calcareous, slightly acidic, and without marked profile development.

The reactions of representative soils of this zone are indicated by the following distribution table:—

——	Number of samples in each range.									
Range, pH	5·2—5·6	5·6—6·0	6·0—6·4	6·4—6·8	6·8—7·2	7·2—7·6	7·6—8·0	8·0—8·4	8·4—8·8	above 8·8
Surface....	1	....	4	2	2	....	....	1	1	....
Subsoil....	....	....	1	3	1	....	....	....	....	1

It is considered that the area represents one of relatively immature soils of the leached group. A leached group of soils in a tropical region where the average rainfall is only 10 to 15 inches per annum may seem a paradox but it must be remembered that a considerable proportion of the precipitation falls in heavy deluges so that the climate temporarily is highly humid and consequently the soils exhibit the characteristics of leached soils.

At least four formations or regions may be recognised in the zone:—

(1) *Nullagine region*: rough range country where spinifex grows alike on the restricted sandy plains and on the rough, skeletal soils of the gravelly and stony hills.

(2) *Warralong region*: rolling spinifex plains where the soils are generally brown and red brown sands and sandy loams.

(3) *Hamersley region*: rough range and tableland country carrying spinifex on the skeletal soils of the hills and with areas of grassland, largely *Eragrostis* spp., on the brown clayey soils of the fertile plains.

(4) *Lyndon region*: undulating spinifex grasslands.

This zone corresponds rather closely with Clarke's (1926) "North West Region."

The climate is similar throughout. The rainfall ranges from 10 to 15 inches per annum, the summer temperatures are notoriously high (Marble Bar is one of the hottest places in the world), and for no month does the average precipitation exceed the evaporation. Exceptionally heavy rains associated with the summer hurricane season are of not infrequent occurrence as exampled by the records of Whim Creek for 24 hour periods:

3rd April, 1898	29.41 inches.
21st March, 1899	18.17 „
6th March, 1900	10.03 „
3rd March, 1903	10.44 „

23.—THE NULLAGINE REGION: 13,300,000 ACRES.

Mulga, as a feature of the landscape, disappears in the range formation north of the Fortescue sunkland and its place is taken by spinifex (*Triodia* spp. and *Triraphis* spp.) steppes with scattered small trees including kanji (*Acacia pyrifolia*), bloodwood (*Euc. lamprocarpa*), *Grevillea pyramidalis*, cork (*Hakea lorea*), etc. Coolibah (*Euc. microtheca*), minerichi (*Acacia Grasbyi*), various grasses, *Cassia* spp., etc., are common in the alluvial areas.

The region has the appearance of a dissected plateau of Nullagine Series, Mosquito Creek Series and intervening granites and is of very rugged and immature topography, particularly in the south. Toward the north, in the vicinity of Marble Bar, there is more high level plain country generally associated with granites dissected by diorite reefs. The scenery is typically rugged: rough hills of dark reddish brown colour, covered with sparse spinifex and scattered scrub. The numerous creeks, where soil conditions are better, are usually associated with a growth of small trees, shrubs and grasses.

While the area is predominantly one of brown to red brown skeletal soils, considerable occurrences of stony surfaced, or serir, soils are noted in the region.

Stony fragments are most commonly of resistant quartz or ferruginous quartzite. Underneath the stony layer is a brownish sandy textured soil with little evidence of profile development. Where the soil is very sandy, serir does not develop and a loose formation, liable to drift under the action of wind, is encountered. On the more productive plains in the north, *e.g.*, Talga Talga and Eginbar, the stony surface or desert pavement is less marked.

Characteristic soil types, which may be considered as intrazonal, develop on the more basic rocks. Outcrops of basalts usually give rise to a brownish red crumbly clay: other basic rocks frequently form a dark grey carbonated soil with magnesite boulders. Patches of calcareous, or opaline, soils occur in the valleys apparently as a result of the precipitation of calcium carbonate as spring waters are warmed by exposure to surface conditions.

Laterite is observed on many of the flat topped hills. Special mention may be made of the ferruginous laterite above a shaly sandstone on Telegraph Hill at Nullagine township.

An interesting characteristic of many of the valleys and plains are huge ant-hills 6 to 8 feet high and pyramidal or conical in shape. In harmony with the rough hills, they are dark red brown in colour.

The Nullagine region is developed for Merino sheep in the more favoured areas. By burning the spinifex on the hills at intervals, a more or less satisfactory growth of herbage may be maintained and much new country is being utilised by this device. A disorder, known as "staggers," develops among sheep on spinifex in this region. Control is apparently effected by feeding salt licks.

24.—THE WARRALONG REGION: 6,800,000 ACRES.

Immediately north of Eginbar Homestead the vegetation changes. The trees grow larger and taller (15 to 20 feet) and white wood (*Atalaya hemiglauca*) and warralong or camel tree (*Bauhinia Cunninghamii*) join the association. Experience shows that the spinifex generally is of better feeding value and much is of the "soft" type more highly prized by stockmen. Other

grasses, herbs, succulents and shrubs assume a more important place in the associations. The formation generally may be described as a semi-desert savannah.

Along the rivers large eucalypts occur in a woodland formation.

Physiographically the region is gently undulating and slopes from the foot of the tableland country to the coast on the north. Outcrops of rough stony hills occur and serve to break the monotony of the plain. An example is the Ord Range near Port Hedland.

Granite is the principal inland geological formation.

Three main groups of soils have been observed:—

(a) Brown to red brown gritty sands and sandy loams with or without a clay accumulation in the subsoil. Some tendency to cementation in the subsoil may be noted. Serir formation occurs but is not as usual as on more southern regions. Patches of heavier soils occur, as also do looser sands, in restricted areas. The better and more productive soils occur along the small streams and valleys.

The chief elements of the vegetation are spinifex (*Triodia* spp., *Triraphis* spp.), wire grass (*Eragrostis* sp.), weeping grass (*Chrysopogon Gryllus*), various other grasses and shrubs (particularly along creeks), *Bauhinia Cunninghamii, Atalaya hemiglauca*, and the ubiquitous kanji (*Acacia pyrifolia*). In various patches, more particularly where the soil is lighter in texture, other acacias are observed (*A. retinervis, A. holsericea*), minerichi, also native walnut (*Owenia reticulata*), *Melaleuca lasiandra, Grevillea leucadendron* and *Hakea lorea* usually as a savannah formation. Eucalypts occur in patches, particularly along creeks where the soil conditions are better.

Where the vegetation has been destroyed some damage from wind action occurs and leads to the formation of "clay pans."

(b) Flats associated with the rivers and littoral or flood plain formations.

Brown and red brown sands, loams and clays, carrying both woodland and grassland or shrub associations, occur along the rivers and along the coast. With traffic, in some patches the soil becomes powdery and liable to wind erosion. Also there are considerable areas of wind eroded country where the vegetation has been destroyed. These patches are commonly known as "claypans" and often show a stony pavement surface. Herbage is difficult to establish on them unless the surface is broken by means of an implement.

In the coastal areas, salt water at shallow depths is frequently encountered and presents a problem in the provision of stock water.

A much wider variety of vegetation grows in these areas so much better favoured for moisture. A woodland association characterises the river banks, eucalypts predominating. Mitchell grass (*Astrebla pectinata*), Flinders grass (*Iseilema membranacea*), Buffel grass (*Pennisetum cenchroides*) and weeping grass (*Chrysopogon Gryllus*), as well as spinifex, represent the grasses, and in the treeless country *Atriplex, Bassia divaricata*, samphire (*Salicornia* sp.) and "lucerne" (*Trigonella suavissima*) are important. The "lucerne" is used for hay purposes.

(c) Coastal sandhills and mangrove flats.

These formations are observed along the coast. Owing to the high tides —up to 25 feet—lower lying areas, subject to flooding by tidal waters, are

mud flats carrying mangroves. The sandhills are similar to those elsewhere along the coast.

In his ecological studies in the region, Anderson (private communication) found that the association of small trees gave the best indication of the grazing value of the country. Thus, the edible *Bauhinia Cunninghamii* and *Atalaya hemiglauca* are associated with the better classes of country, and the inedible *Acacia* spp., *Owenia reticulata* and *Grevillea leucadendron* with the less valuable areas where the soil is more sandy. The species of spinifex occurring in both associations are practically the same. The feeding value of the various types of edible spinifex was dependent on the nature or fertility of the soil type on which it was growing, rather than on the species. Any of the types of "soft" spinifex may be found growing in either association but other perennial grasses and annuals are mostly confined to the better classes of country.

25.—THE HAMERSLEY REGION: 10,600,000 ACRES.

The dissected tableland between the Ashburton River and the Warralong region has been included in the Hamersley region.

This area consists principally of rough ranges with skeletal soils of the brown group, and the undulating, grassy, brown soil plains of the coastal areas.

These coastal areas are known as the Roebourne Plains. The soils of the grasslands are generally clayey in texture but areas of lighter loams occur associated with spinifex, and rough spinifex covered hills bound the plain. Along the creeks and rivers belts of eucalypts and acacias have established. Stunted kanji and gema bush grow on some sites in the grassland.

The tableland and range country is covered with spinifex, kanji (*Acacia pyrifolia*) and snakewood (*Acacia eremaea*) growing in very stony shallow, brown soil. From Millstream southwards eucalypts appear to replace the kanji. In the valleys, rich flats of brown clayey soils have formed. These are typically grassland soils and carry *Eragrostis* spp., Mitchell grass (*Astrebla pectinata*), Flinders grass (*Iseilema membranacea*), etc. With the grasses are patches of kanji, snakewood, gema bush and wattle.

South of Mt. Florance belts of mulga occur on the lower slopes and grasses in the valleys. This section obviously falls in the transitional Ashburton region.

26.—LYNDON REGION: 5,900,000 ACRES.

G. F. Melville (private communication) has suggested that the country between the Lyndon River and Peedamullah Station may be appropriately mapped as a region of the brown acidic soils of the semi-desert steppes. This area is probably one of the best grazing regions of the pastoral areas and consists largely of red and red brown sandy soils of the spinifex plains, restricted areas of rough stony soils of the rises and hills, and brown clay soils of the Ashburton flood plain and other rivers.

The spinifex plains are sandy, more or less undulating, and carry either a pure spinifex stand or spinifex associated with kanji and snakebush. Ephemerals such as *Trichinium* spp., grasses and other plants grow with the spinifex. Where claypans occur, open grassland and patches of acacia scrub occur. Lines of consolidated sandhills are observed in some parts.

The rough, stony hills carry spinifex and scrubby acacias including snakebush and kanji. The soils are of the skeletal group.

Along the Ashburton and other rivers are extensive plains. These are usually open grassy flats of brown clayey soils and are broken by scattered clumps of curara, snakewood and other acacias. Flood gums (*Eucalyptus rostrata*) grow along the channels.

The western coastal areas are largely spinifex covered, red sandy soils —either gently undulating plains or low sandhills—with patches of heavier stony country and limestone outcrops. For a width of a few miles along the coast grey sandy soils occur.

Geologically, the region is principally Cretaceous and Cainozoic in age.

F.—ZONE OF PINKISH BROWN CALCAREOUS SOILS OF THE NULLARBOR PLAIN DESERT SHRUB STEPPES: 16,900,000 ACRES.

A zone of Tertiary limestones in the south-east portion of Western Australia is associated with a desert shrub steppe and has been defined as one region and named the Nullarbor region.

27.—NULLARBOR REGION: 16,900,000 ACRES.

The region, which corresponds to Clarke's (1926) Nullarbor region, is a featureless plain carrying a sparse vegetation of low saltbush (*Atriplex*) and blusbush (*Kochia*). On the marginal areas a few small trees and shrubs such as cheese wood (*Pittosporum phillyraeoides*), acacias and melaleucas grow in dongas or shallow depressions, but on the plain proper along the Trans-Australian Railway Line nothing but the sparse saltbush and bluebush about one foot high is observed.

Although the plain appears perfectly flat, in actual fact is is very gently undulating and from the air appears pock-marked by shallow dongas.

The travertine seems to occur within a few inches of the surface and is covered by a layer of pinkish brown calcareous material of a loamy to clayey texture, which may be described as soil. Deflation appears to remove this material fast enough to maintain permanent immaturity. In 1930, four samples of soil were collected near Forrest by Mrs. Johnson (then Lecturer in Botany at the University of Western Australia) and examination gave the following results:—

Analyses of soil samples from the Nullarbor Plain at Forrest and from a tree belt 15 *miles north of Forrest.*

Serial No.	Depth.	Description.	Calcium Carbonate.	Salt (NaCl) from Cl.	pH.	
					Quinhydrone, 1 : 5.	Glass electrode, 1 : 5.
	inches.			%		
A271	0—6	Dark fawn silty clay	rich	0·07	8·50	8·88
A272	0—6	Fawn silty clay from bluebush area	rich	0·38	7·72	8·08
A273	0—6	Fawn silty clay from *Trigonella* clover area	rich	0·02	7·56	7·94
A274	0—6	Light brown silty loam from tree belt 15 miles north of Forrest	rich	0·007	8·06	8·62

The rainfall of the area is very low—probably averages between 5 and 10 inches per annum—and long drought periods severely tax the vitality of the vegetation. Following rains, a rich, ephemeral carpet of grasses and herbage appears.

The travertine is interesting as it contains small, black, globular inclusions unlike any other limestone formations yet observed in Western Australia. The nature and origin of these inclusions are at present unknown.

Ferruginous gravel or lateriate is not known to exist.

The pastoral possibilities of the region appear to the very scanty.

G.—ZONE OF PINKISH BROWN CALCAREOUS SOILS OF THE SEMI-DESERT SCRUB ASSOCIATED WITH THE NULLARBOR PLAIN—31,000,000 ACRES.

On account of the paucity of information this zone is mapped as one region and named the Giles region after Ernest Giles who traversed it in 1875 (Giles, 1889).

28.—GILES REGION: 31,000,000 ACRES.

West of Naretha, on the Transcontinental railway line, the vegetation changes to acacia scrub (mulga) with saltbush and bluebush as undergrowth. The soils resemble those of the Nullarbor region in being pinkish brown in colour and possessing a calcareous travertine in the subsoil. The surface soil, however, is deeper and probably reflects the protection of the vegetation and a slightly higher rainfall—probably about 9 to 10 inches per annum.

Giles describes the country further north as being covered with mallee scrub (*Euc. dumosa*), mulga (*Acacia* spp.), cypress-pine (*Callitris* sp.), *Casuarina* sp., quondong (*Santalum acuminatum*) and poplars (*Codonocarpus cotonifolius*) and an undergrowth of spinifex and shrubs. Blackboy (*Xanthorrhoea* sp.) is reported. The soil is apparently reddish and sandy, sandhill formations are common, and salt lakes of frequent occurrence.

The land classification of McLeod (1922) indicates that this belt of mulga, myall and some mallees, with an undergrowth of saltbush and bluebush, continues south of the Transcontinental railway and reaches the coast in the vicinity of Eyre. It also forms a buffer region between the Nullarbor Plain and the south coast in Western Australia.

It seems likely that the soils of the Giles region resemble those of that portion of South Australia north and east of the Nullarbor Plain. They certainly form a soil zone quite distinct from the more western portions of Western Australia in the same vegetation and climatic belt. In fact, the soils of the Giles region show a closer affinity to those of the Nullarbor region than of other regions recognised.

Laterite is not known to occur.

The pastoral possibilities of the northern portions of the Giles region are largely unknown, but difficulties in obtaining suitable water supplies probably present the chief problem. It is recognised that the coastal portions of the region carry some of the finest pasturage of the low rainfall areas of the State but the prevalence of brackish water renders appropriate pastoral development difficult.

McLean (1926) reports the analyses of two samples of water from between Eucla and the Transcontinental line as follows:—

Sample.	Magnesium.	Salt (NaCl).	Total water soluble salts.
	grains per gallon.	grains per gallon.	grains per gallon.
1	36·4	818·6	961·2
2	36·4	818·6	963·2

The narrow fringe of coastal country between the limestone cliffs and the sea carries mallee and could be considered as part of the zone of grey and brown calcareous solonised soils of the eucalyptus woodland. However, the wealth of saltbush and bluebush conveniently associates it with the southern part of the Giles region and for that reason this strip is included with the Giles region.

H.—THE BROWN SOIL ZONE OF THE NORTHERN TROPICAL WOODLANDS, SAVANNAHS AND GRASSLANDS: 79,600,000 ACRES.

Our knowledge of the soils of the tropical areas is very meagre but a general picture of the zonal features has been obtained as a result of a visit by Prescott (1937). In addition, a number of geological, botanical and agricultural expeditions* have been made and these, together with the recent reports of Surveyors H. Barclay, S. J. Stokes, and T. Cleave, afford a general picture of the area.

The main mass consists of a dissected and eroded plateau, or conoplain to use Jutson's term (Jutson (1934), p. 42), generally 1,000 to 2,000 feet in elevation. On the north is a rugged, becliffed coastline, with huge gulfs and indentations, and rivers running in deep gorges with wall-like sides. The west, south and east boundaries of the conoplain are delineated by the King Leopold Ranges, the Albert Edward Range, and the Carr Boyd Range. Outside of these boundaries is a lower and much more highly eroded plateau. The valleys of the various rivers in this latter area are most important pastorally and it is here the zonal soil type has developed. The chief rivers are the Fitzroy, Lennard, Robinson and Ord systems.

The geological formations of the conoplain are mainly massive Precambrian sandstones and lava flows probably of the Nullagine series. It is fringed on the west, south and east by Mosquito Creek formations. A mass of granite is sandwiched between these two sedimentary series on the south-east. Wade (1936) reports that the most important group of sedimentary rocks in the south-western portion of the zone (West Kimberley area) belongs to the Permian System and is regarded as a likely source of oil. Devonian limestones also occur extensively in this area and rest, with marked unconformity, on the Precambrians. The Cape Leveque Peninsula and south-western coastal areas are Jurassic in age. On the extreme east, the limestones and basalts of the Antrim Tableland are of Cambrian age.

Prescott (1937) has summarised the climate and vegetation characteristics. A study of the available records shows that the rainfall is markedly seasonal and practically confined in incidence to the summer months. The

*Easton, Fitzgerald, Brockman, Wise, Evans & Lefroy, Payne.

rainfall per wet day is high (about 0.50 inches) and both this factor and the length of the wet season decreases from north to south. The most important, and unfortunate, feature of the rainfall is its variability, which is approximately twice as great as in parts of Northern Nigeria, for instance, where the climate is otherwise similar, but a large population is supported.

Prescott quotes the following information:—

Centre.	Mean anuual rainfall.	Proportion of rain falling Oct.–Mar.	Rainfall per day.	Length* of wet season.
	inches.	per cent.	inches.	months.
Port George IV.	53·9	91	0·63	5·2
Drysdale River	36·1	91	0·52	5·2
Ivanhoe	32·8	94	0·62	4·1
Wyndham	26·9	94	0·44	4·2
Argyle Downs	26·1	94	0·50	4·0
Derby	25·8	88	0·55	4·2
Broome	23·0	85	0·56	4·1
Hall's Creek	20·8	91	0·36	3·0
Ord River	19·9	94	0·45	3·4
Noonkanbah	19·2	92	0·49	3·0

* Length of wet season is taken as the period during which the monthly ratio of rainfall to saturation deficit exceeds the value of 5.

Davidson (1934) estimates that, except in the extreme north, precipitation exceeds evaporation in January and February only.

The high rainfall per wet day and the occurrence of torrential rains are important factors in the degree of leaching of the soils which do not appear to be generally calcareous except where the texture is heavy or special geological formations occur.

Gardner (1923) has described the principal vegetation associations of the zone. In brief, they may be summarised as follows:—

(1) *Rain or Corridor forests.*

Fringing the rivers of the Brockman and Drysdale regions are strips, up to 200 yards wide, of moist black soils. The moisture persists throughout the dry period and a dense rainforest, practically devoid of eucalypts, has become established. The Leichardt tree (*Sarcocephalus*), the banyan and other species of *Ficus*, a kapok tree, cajuput (*Melaleuca leucadendron*), etc., are characteristic. Mangroves flourish in the soft, black mud of the coastal areas.

(2) *Sclerophyll forests or woodlands.*

In the Drysdale region, away from the water courses, a typical sclerophyll forest association, resembling the jarrah forest of the south-west in general appearance, has established in the lateritic and skeletal soils. The chief trees are messmate (*Eucalyptus tetrodonta*), ironbark (*Erythrophleum chlorostachys*), stringy bark (*Euc. tetrodonta*), woollybutt (*Euc. miniata*), pindan wattle (*Acacia tumida*), *Jacksonia* spp., *Grevillea* spp., Pandanus, and fan palms (*Livistona*). Soft spinifex and some grasses are reported.

(3) *Savannah woodlands.*

Probably the savannah woodlands are the most important and extensive vegetation associations of the zone. Two main types occur.

(a) Undulating basaltic country. Open woodlands of grey box or coolibah (*Euc. microtheca*) are most characteristic and bloodwoods (*Euc. pyrophora* and *Euc. terminalis*) are fairly common.

With these trees, fine grasses, such as Flinders grass (*Iseilema membrænacea*) and kangaroo grasses (*Themeda* spp.) grow in profusion.

(b) Sandstone country.

This is largely steep scarps and ranges and carries a denser vegetation including cypress-pine (*Callitris intratropica*), messmate (*Eucalyptus tetrodonta*) and woollybutt (*Euc. miniata*). The "grasses" are of a coarser and poorer type. Sugar grass (*Andropogon* sp.), spinifex (*Triodia*) and *Cyperaceae* are common.

(4) *Low tree savannah woodlands.*

The sandy soils of the pindan* areas commonly carry a scattering of more or less stunted trees, for example, a bloodwood, and a dense undergrowth of pindan wattle (*Acacia tumida*), such shrubs as konkerberry (*Carissa*), an ironwood (*Terminalia circumalatæ*), and coarse grasses such as *Andropogon* spp.

(5) *Grasslands and savannahs.*

Pastorally the grassland and savannah associations are of very considerable importance. They occupy the heavier textured soils generally, which do not appear to favour trees, and appear to predominate where the rainfall is lower or is physiologically lower on account of soil texture.

Three types of association may be mentioned in this group.

(a) Open grasslands, almost devoid of trees, are characteristic of the heavier textured brown and "black" soils of the plains. Mitchell grass (*Astrebla pectinata*), Flinders grass (*Iseilema membranacea*), kangaroo grasses (*Themeda* spp.), and bundle bundle are the chief grasses, and *Bauhinia Cunninghamii* is probably the most characteristic tree. Gutta-percha (*Excaecaria parvifolia*), a small tree, is common on the heaviest soils where the water supply is adequate.

(b) Dense cane grass (often up to 10 to 14 feet tall) and sugar grass (*Andropogon affinis*) grow on the sandier slopes.

(c) Spinifex (*Triodia* spp.) is characteristic of the stony range country receiving less than 30 inches of rain per annum and of the soils generally where the rainfall is low and restricted to about three months of the year or less.

The Soils.

Until Prescott's visit (1937) the zonal relationships of these soils were obscure. He recognised a similarily between the zonal soils of this area and of the Murray valley and has tentatively proposed to group them with the grey and brown, and "mallee" soils of the south, which are essentially alkaline and calcareous. It seems to the writer that more evidence is needed

*Pindan is a native name referring to the land away from the rivers and permanent water.

to establish such a general relationship, as a body of information points to a higher degree of leaching and a lower degree of alkalinity than is exhibited by the soils of the semi-arid south.

The reactions of a number of samples from the zone, including a profile examined by Prescott (1937) at Noonkanbah Station, are shown in the following distribution table:—

——	Number of samples in each range.									
Range, pH	5·2—5·6	5·6—6·0	6·0—6·4	6·4—6·8	6·8—7·2	7·2—7·6	7·6—8·0	8·0—8·4	8·4—8·8	above 8·8
Surface	2	3	....	2	1	1	3	2	....	....
Subsoil	....	4	5	....	....	2	1	2	2	1

The number of acidic soils is of considerable interest in discussing the affinities of the soils of this zone.

Competent observers agree that the principal soils are of the brown type. Surveyor Cleave (private communication) has likened the soils of the peninsula south of Yampi Sound to the red brown earths at York. Surveyors Barclay and Stokes have made similar observations along the Northern Australia boundary and Dr. A. Wade of the Freney Kimberley Development Company mentions brown soils on certain basaltic plateaux and on the "blue clay" geological horizon in the Oscar Range district.

The brown soils appear to fall into four groups—

(a) The heavy textured soils of the river terraces which resemble the heavier soils of the Murray and Murrumbidgee valleys. Prescott describes one profile at Noonkanbah as being uniformly brown in colour, cloddy in structure, slightly calcareous in the subsoil and highly gypseous below 35 inches. These soils carry a grassland or open savannah association.

(b) The reddish sandy soils—the so-called "pindan" soils. These soils show a low east-west sandhill formation and are densely covered by the low tree savannah woodland associations. They provide accommodation for stock during the "wet" season.

(c) Brown clayey soils of the "blue clay" geological horizon of the Oscar range district and on certain basaltic formations (described by Dr. A. Wade).

(d) Brown sandy loams and loamy sands of the savannah woodlands. Cleave (private communication) has described these in the valleys of the peninsula south of Yampi Sound as more or less stony sandy loams carrying a woodland of grey box (*Eucalyptus ? Spenceriana*), woollybutt (*Euc. miniata*), white gum (*Euc. papuana*) and cajuput (*Melaleuca leucadendron*) with abundant grasses and shrubs and small trees such as konkerberry (*Carissa*) and cotton tree (*Cochlospermum heteroneurum*).

Intrazonal soils are black soils of certain valley formations in the Ord Valley, on Cambrian basalts of the Antrim tableland and occasionally on basalts of the Brockman region, and on Devonian limestones in the Oscar Range (Dr. A. Wade). These black soils typically carry good quality and, also, coarse grasslands or open savannahs, and are of very heavy texture. During the dry season they crack badly and often open up into crevices 6 inches wide and 3 feet deep. However, many of the popularly described "black" soils undoubtedly belong to the brown soil group. Yellow and greyish yellow and yellow brown sands, often with ferruginous gravel (laterite) in

the subsoil, constitute another important intrazonal soil type. An extensive area of this type, 30-40 miles across, occurs south-east of Wyndham. Barclay (private communication) reports this to be vegetated by a type of *Melaleuca* resembling *M. thuyoides* in habit. Similar sandy soils were observed on the Border Survey.

Areas of restricted drainage are associated with light grey to yellowish grey powdery and loamy soils generally associated with cajuput (*Melaleuca leucadendron*) in the west and with spinifex and scattered trees in the east. The grey anthills of these soils are most characteristic.

Other intrazonal soils are the moist black soils of the corridor rain forests of the northern river gorges, the red basaltic soils described by Easton and observed by Barclay on the Antrim Tableland, and the buff soils of the moving sandhills. Wade (private communication) has observed that the soils of the fixed sandhills are characteristically red in colour but where movement is taking place the soils are a buff colour.

Laterite is a prominent feature in many parts of the zone but particularly in the Drysdale region of the north. Fitzgerald (1907) records ferruginous gravel in the pindan country of the May River east of Derby and in the Throssell River, the Isdell Range and the Sprigg River areas in the conoplain (Hann region). Cleave (private communication) mentions an occurrence of lateritic material on the Townshend River, Oobagooma Station, near Derby.

A sample of the yellowish sandy soil type collected by Surveyor S. J. Stokes on the border survey showed a subsoil rich in pisolitic, ferruginous gravel of the laterite type. Similar profiles are common in the southern temperate part of the State.

By far the most extensive intrazonal soils are of the skeletal group. The rough range country, which is typified by the Hann region, is typically eroded, and rough, stony skeletal soils are the main formation. It is the occurrence of these soils which largely limits the development of the Kimberley Districts as they are of low fertility and support a woodland vegetation of low pastoral value.

On the sandstones and quartzites, which Easton estimates to occupy over 70 per cent. of the area of the range country, the soils appear generally to be of a grey colour. However, brown skeletal soils have been described by Cleave in his observations in the peninsula south of Yampi Sound. These belong to the brown soil group.

The zone is predominantly a pastoral country. Early development was practically entirely for cattle which took advantage of the coarse growing grasses and was largely confined to the Fitzroy region where the topography presented no serious difficulties. Some development has proceeded in the Hann region in localities where soil and topographic features are more propitious but the conoplain generally is too rough and the soils inadequate for pastoral activities.

Sheep raising is assuming greater importance as the development has proceeded and more adequate water provision is made. A number of important stations on the Fitzroy River, for example, Noonkanbah, are successfully engaged in wool production. It is thought that there will be further expansion in the sheep industry in the Kimberleys in the future.

Practically no agricultural activity is reported from the zone. Various estimates of the extent of agricultural land have been made. Fitzgerald (1907) estimated that over a million acres of country were suitable for the cultivation of tropical products. There is no doubt that areas of suitable agricultural soils exist in this soil zone but development is rendered difficult by such factors as variability of the rainfall, climatic conditions unattractive to a white population, and, to a lesser extent, accessibility to markets and supplies.

The brown soil zone of the tropical savannahs and grasslands has been divided into four soil regions, largely on the basis of physiographic and geological factors. Two of these regions, the Brockman and Drysdale regions, might possibly be considered as sub-regions of the Hann Region.

29.—FITZROY REGION: 39,900,000 ACRES.

The Fitzroy region is occupied by the main river basins, and the low dissected plateau of the southern, eastern and western portion of the zone. The soils have developed zonal features and are the basis for the classification of the main soils of the north of the State. Brown soils predominate and carry the chief pastoral activities of the north. Grassland associations, savannahs and savannah woodlands are the predominant ecological features.

In an earlier regional classification this region was divided into two. The western portion, including the Leveque Peninsula and the coastal country west of Broome, was separated as a region on account of the predominance of sandy country of the "pindan" type. Later consideration showed that this type is common throughout the region and the definition of another region seems undesirable in the light of our present scanty knowledge.

The Antrim Tableland east of Hall's Creek could be considered as a region but paucity of appropriate information renders it advisable not to attempt subdivision at the present time.

Little is known of the chemical nature of the soils. Analyses made by the Government Chemical Laboratory about 20 years ago showed them to be somewhat low in plant foods (Tables 15 and 16) but the pedological, pastoral or agricultural significance of these results is obscure. Recent analyses of 3 samples from Ivanhoe Station in the Ord River valley have been made and are more informative.

The samples are described as follows:—

(1) "Red" soil of an open savannah carrying white gum (*Euc. papuana*), red gum (*Eucalyptus* sp.), cabbage gum (*Euc. clavigera*), native couch (*? Cynodon dactylon*), and kangaroo grass (*Themeda* sp.).

A2062, 0-9 inches deep, a chocolate brown micaceous, light fine sandy loam.

A2603, 9-18 inches deep, a rich brown micaceous, fine sandy loam.

(2) "Black" soil carrying Flinders grass (*Iseilema membranacea*) and Mitchell grass (*Astrebla pectinata*), and sparsely timbered with *Bauhinia Cunninghamii*.

A2064, 0-12 inches deep, a greyish chocolate light loamy clay (brownish, blackish grey when wet).

The analyses of these samples are given in Table 14.

TABLE 14.

Analyses of samples of soil from the Ivanhoe Station, Ord River, Kimberley, representing the Fitzroy Region.

Sample Number	A2062	A2063	A2064
Depth (inches)	0–9	9–18	0–12
Mechanical Analysis—			
Coarse sand %	3·8	5·2	4·5
Fine sand %	73·3	63·2	44·4
Silt %	8·5	9·7	12·8
Clay %	11·7	18·2	32·3
Loss on acid treatments % ...	0·8	0·8	1·3
Moisture %	1·6	2·1	3·7
Loss on ignition %	2·7	3·0	4·6
Calcium carbonate %	0·4	0·6	0·5
Chemical Analysis—			
Nitrogen %	0·056	0·050	0·062
Organic carbon %	0·595	0·344	0·764
Carbon : nitrogen ratio % ...	10·6	6·9	12·3
pH (1 : $2\frac{1}{2}$, quinhydrone) ...	7·05†	7·49	7·24
*Potash, K_2O %	0·396	0·383	0·413
*Phosphoric oxide, P_2O_5 % ...	0·036	0·021	0·020
Replaceable Bases—			
Total—m.e. per 100 gm. soil ...	11·75	13·29	24·13
Total bases—m.e. per 100 gm. clay	100	73	75
Calcium—percentage of total rep. bases	57	54	50
Magnesium—percentage of total rep. bases	37	40	46
Potassium—percentage of total rep. bases	5	4	3
Sodium—percentage of total rep. bases	1	2	1
Replaceable Hydrogen—m.e. per 100 gm. soil	1·5	1·3	2·7

*Soluble in concentrated hydrochloric acid. †Glass electrode, 6·79.

These samples indicate that the soils of these types are rich generally, but are low in phosphate.

Details of two interesting traverses in this region are available and may be summarised here:—

(1) Yampi Sound to Oobagooma Station—Surveyor T. Cleave:—

0-16 miles. Rough, quartzitic hills with a few granitic and basaltic outcrops. The valleys are narrow and very stony and carry a woodland of woollybutt (*Euc. miniata*), grey box (*Euc. ? Spenceriana*) and bloodwood. The area is well grassed and carries, in addition, a little soft spinifex. The soil is a brown sandy loam but is very stony and of the skeletal type.

16-30 miles. The valleys are wider—up to one mile—flat and well grassed, and carry a grey box woodland with konkerberry (*Carissa*) and cotton tree shrubs. In this section the soils are brown and light brown in colour and stony only in patches. Very rough, flat-topped, quartzitic hills are characteristic.

30-50 miles. This area includes the headwaters of the tributaries of the Robinson River. The valleys are flat, several miles wide, and broken by quartzitic mesas. Tall white gum (*Euc. papuana*) and cajuput (*Melal. leucadendron*) grow in the grassy valleys and grey box (*Euc. ? Spenceriana*) on the higher slopes. The soils are of the brown type.

The first 30 miles of this well watered country is reported to be too rough for pastoral development.

South of this section is encountered the pindan country with poor scraggy timber (wattle (*Acacia tumida*), cajuput, and beefwood) and yellowish to yellowish grey soils, more clayey than the brown soils above.

(2) Border survey—north coast to 294 miles south—along the 129° E meridian. (West Australian, November 22nd, 1937, reporting Surveyors H. Barclay and S. J. Stokes):—

0-15 miles—mud flats, mangrove belts.

15-16 miles—grassy country.

16-34 miles—dirty grey, loose sand carrying messmate (*Euc. tetrodonta*) and woollybutt (*Euc. miniata*).

34-38 miles—Weber Ra.—very rough quartzitic country.

38-58 miles—black soil plain with sparse timber and Flinders grass (*Iseilema membranacea*). The soil is a heavy clay and in the dry period cracks badly. The cracks may be as much as 6 inches wide and 3 feet deep.

58-69 miles—Burt Ra.: very rough and difficult sandstone range, 800 to 1,000 feet high.

69-81 miles—sandy country with deep creeks. Dense cane grass (*Rottboellia rottboellioides*) up to 12 to 14 feet tall.

78½ miles—Obelisk.

81-111 miles—black soil plain with basalt boulders and broken by basalt hills and ridges. Carries good Mitchell grass (*Astrebla pectinata*) and Flinders grass with cane grass and sugar grass (*Andropogon affinis*) on the slopes.

111-134 miles—dissected plateau country with very stony soils of the Behn River system—"red" soils reported.

134-158 miles—Negri River Plains and other plains with sandy stretches and ranges. The plains are badly affected by wind erosion—Probably brown soils.

158-165 miles—woodland of trees, grass and spinifex.

165-192 miles—limestone and basalt plateau. Rough dissected country with deep gorges and piled basalt boulders. Vegetation—largely thick matted spinifex.

192-208 miles—flat plain of greyish crumbly clay on a black hard clay which cracks badly when dry. Flinders grass is the chief grass.

208-235 miles—rolling country with spinifex and sparse acacia, leading to red gritty soil with a hardpan said to resemble coffee rock. This type carries mallee types of eucalypts and *Melaleuca* scrub as well as spinifex.

235-245 miles—open downs.

245-294 miles—sandy ridges and sandy troughs.

294 miles southwards—a sandstone range carrying spinifex, mallee eucalypts, and sparse acacias.

The occurrence of hardpan in the red gritty soil of the 208-235 mile section is of interest and suggests a possible relationship with the hardpan soils of the acacia semi-desert scrub zone.

30.—HANN REGION: 28,900,000 ACRES.

The Hann Region consists of a series of ranges and tablelands with intervening plains, and forms a low dome or conoplain. Sandstones and quartzites are the chief rocks but areas of basaltic intrusives occur. The area is dissected by streams and gorges and is exceptionally rough, but the plains, often quite extensive, are suitable for pastoral development where accessible. The chief vegetation association is the savannah woodland which has been described above (page 178).

Little is known of the soils except that they are predominantly skeletal. Grey soils appear to occur on the sandstones and quartzites, but red and black soils are described on the basaltic rocks. Brown soils should be the normal type.

31.—BROCKMAN REGION: 5,000,000 ACRES.

Between Walcott Inlet and Prince Frederick Harbour and inland as far as Mount Agnes and Mount Hann lies a region of fairly high rainfall (33 to 50 inches per annum) and in which the very rough sandstone country is intersected by deep gorges with wall-like sides.

In these gorges run rivers of considerable magnitude and associated with these rivers are strips of moist black soils carrying the "corridor" rain forests. In other respects the conditions appear to resemble closely those of the Hann region. The soils are largely skeletal in type but brown soils should be the "normal" type. Semi-humid red soils should occur in the wetter parts of the region but have not been observed.

32.—DRYSDALE REGION: 5,800,000 ACRES.

The extreme northern portion of the zone is likewise more generously provided with rain (33 to 40 inches per annum) but differs from the Brockman region in the occurrence of much ironstone gravel—undoubtedly laterite —with the sandstone formations. The sclerophyll woodland (see page 177) of the Drysdale region is a further regional distinction. The region forms an extension of the very rough sandstone tableland with basaltic flows of the Hann and Brockman regions and is deeply cut by river gorges.

Little is known of the soil conditions except that laterite gravel is common and that skeletal soils occupy the bulk of the area. Red soils would be expected in the wetter portions of the region but the normal soils generally should be of the brown type.

I.—THE ZONE OF RED SANDS OF THE CENTRAL DESERT SANDHILLS—143,000,000 ACRES.

The central eastern portion of the State may justly be described as desert. As with other great deserts of the world, it is by no means uninhabitable, but, at the present time, the population is restricted to nomadic abori-

ginals. The climate is certainly desertic but details of the conditions are unknown. The average annual precipitation is probably between 5 and 10 inches and the variability is most probably high. Summer temperatures are high and winter temperatures mild in comparison with most continental climates as it is likely that minima rarely fall below 20° F.

Geologically the strata range from the ancient Nullagine Series and probably Mesozoic or Tertiary formations of the central and southern portions to Permian series in the north-west section. Over most of the area the rocks are covered by rolling spinifex covered sandhills but scattered outcrops and breakaways break the monotony. Artesian water is reported in the Permian structures and here, too, there is a likelihood of occurrence of oil-bearing strata.

Clarke (1926) has divided this zone into two natural regions which he has named Carnegie and Canning, respectively. The Canning region occupies the Permian area where artesian as well as surface water may be obtained As the soil and vegetation conditions appear to be similar throughout the zone it has been here regarded as one region and is named the Carnegie region in honour of D. W. Carnegie (1898), the first explorer to traverse it thoroughly.

33.—CARNEGIE REGION: 143,000,000 ACRES.

This area of rolling, red sand dunes, fixed by spinifex and desert gums, proved very formidable to early explorers but has more readily yielded to later investigations aided by modern equipment. Carnegie (1898) was one of the early explorers and has very graphically described his experiences and the nature of the country. His book leaves an indelible impression of an interminable sea of parallel red sandhills. A little mulga and such plants as parakelia (*Calandrina* spp.) may grow in the troughs and spinifex and desert gums on the ridges. A few meagre native soaks and gnamma* holes appeared to be the only water supply. Talbot (1928) has described the country along the Canning Stock route in the north-western portion of the region. As representative of the area may be cited the country north and east of Lake Disappointment. Here the sandhills run East South East and West North West and are covered by spinifex and a light desert scrub and some mulga and poplar. Bloodwood (*Eucalyptus ? lamprocarpa*) occurs on some of the flats and mulga on the stony slopes of breakaways and hills. He mentions the Runton Range of steep red sandhills as much as 100 feet high. Canning was very successful in finding water along the stock route:—

Well No.	Depth.	Supply.	Value for Stock.
	feet.	Gal. per hour.	
6	11½	1,800	First class.
7	70	160	Excellent.
8	60	550	Good.
9	14	1,360	Good.
10	70½	250	Good.

Observations concerning the country in the vicinity of the Rawlinson Ranges, Mt. Carnegie and Bonython Range have been made by Ellis of the Western Australian Geological Survey (private communication). It is

*Gnamma holes are small holes in rocks which hold water. *See* Jutson (1934), p. 307.

described as a plain about 2,000 feet above sea level, with ranges up to 600 feet above the level of the plain scattered through it. The plain consists largely of red sand ridges about a quarter of a mile apart and carrying spinifex and *Eucalyptus eudesmoides* on the ridges. In the intervening depressions the typical plants are desert oak (*Casuarina Decaisneana*) and occasional patches of mulga where the soil is harder and more loamy in texture.

For a distance of 8 to 10 miles around the ranges the soil and moisture relations appear better, as mulga is more prevalent and becomes dominant on the alluvial outflows. With the mulga may be observed spinifex, grasses, and, sometimes, kurrajong. Whitewash gum (*Eucalyptus papuana*) is typical of the larger valleys and outwashes. Small patches of saltbush country may, at times, be encountered.

The ranges are largely of Nullagine quartzites indurated on the surfaces. The typical tops resemble residuals of an old peneplain formation. No evidence of laterite or of the Murchison Region hardpan was observed.

A number of salt lakes are known to occur in the region but further details are needed before any description could be attempted.

Talbot (1928) has observed that the sand is moving in a west and north-west direction and is piling up on the east and south east sides of the hills. From this, he concludes that the Carnegie region is gradually extending westward.

Except in the north-west coastal areas, the pastoral possibilities of the area appear to be very unpromising and mineral wealth has not been indicated by geological surveys.

VI.—RECAPITULATION.

In order to systematise the information available concerning the soil and ecological conditions of Western Australia, the State has been subdivided into 9 soil zones, or main soil groups, and 33 regions. The majority of the soil zones are representative of Australian-wide formations but at least two, the red and brown acidic soils of the acacia semi-desert scrub and the brown acidic soils of the semi-desert steppes, appear to be largely restricted to Western Australia. Further subdivision of the soil zones into regions on the basis of topographic, vegetation and soil features has led to the recognition of 33 regions. In each region these conditions are generally similar and, in consequence, agricultural and pastoral activities and problems will be grouped into similar divisions.

A general and ecological description of each region has been given. In the broadest outline, this information may be summarised as follows:—

A. *Zone of grey, yellow and red podsolised, or leached, soils of the temperate sclerophyll forests*—12,930,000 acres (page 129).

1. Swan littoral region: Jarrah, marri, wandoo and tuart sclerophyll forests of the coastal plain—4,400,000 acres (page 131).

2. Darling peneplain region: Jarrah, marri and wandoo sclerophyll forests of the Darling Ranges—3,900,000 acres (page 136).

3. Frankland region: Karri, jarrah and marri wet sclerophyll forests and wet heaths of the south coastal areas—4,630,000 acres (page 137).

B. *Zone of red brown earths of the eucalyptus—acacia woodlands*—27,460,000 acres (page 140).

4. Dwarda region: Yellow, grey and brown gravelly soils of the wandoo sclerophyll woodland—4,600,000 acres (page 142).

5. Irwin region: red brown soils of the york gum and jam woodlands and sand heaths—7,950,000 acres (page 143).

6. Avon region: red brown and grey soils of the york gum and jam woodlands—also wandoo, mallet, yate, salmon gum and morrel soils—6,700,000 acres (page 144).

7. Stirling region: grey and brown soils of moort, wandoo and yate woodlands, mallee and sand heaths—2,800,000 acres (page 146).

8. Eyre region: grey sand heaths and gravelly soils of the south coastal areas—5,410,000 acres (page 146).

C. *Zone of grey and brown calcareous, solonised soils of the low rainfall eucalyptus woodlands* ("mallee" soil zone of Prescott)—73,100,000 acres (page 149).

9. Corrigin region: grey and brown soils of salmon gum, gimlet and morrell woodlands, mallee and sand heaths—5,400,000 acres (page 154).

10. Merredin region: brown, red brown and grey soils of similar vegetation associations—7,900,000 acres (page 155).

11. Fitzgerald region: grey and brown soils of salmon gum, gimlet, morrel and redwood woodlands, mallee and sand heaths—11,900,000 acres (page 155).

12. Coolgardie region: brown, red brown and grey soils of the salmon gum, gimlet, morrel, blackbutt and salt bush woodlands and sand heaths—23,000,000 acres (page 157).

13. Zanthus region: brown and grey soils of the salmon gum, gimlet, morrel and redwood woodlands with salt bush, blue bush and sage bush—14,500,000 acres (page 158).

14. Ninghan region: brown and red brown soils of the salmon gum, gimlet, morrel, and york gum woodlands and sand heaths. Hardpan is a common feature of many soil types—7,600,000 acres (page 159).

15. Hartogs region: brown and red brown soils, carrying various eucalypts and acacias, and sand heaths—2,800,000 acres—(page 159).

D. *Zone of red and brown acidic soils of the acacia semi-desert scrub-mulga, etc.*—204,000,000 acres (page 160).

(a) Regions of hardpan soils—164,000,000 acres:

16. Murchison region: red and brown serir, hardpan soils of extensive mulga plains, with scattered ranges and hills—43,800,000 acres (page 163).

17. Yalgoo region: undulating country of brown and red brown serir, hardpan soils and lateritic types—19,100,000 acres (page 164).

18. Barlee region: red and brown hardpan soils of the mulga scrub, spinifex plains and saltbush-bluebush plains—44,100,000 acres (page 165).

19. Warburton region: red and brown soils transitional with the desert sandhill zone:—Spinifex covered plains and sandhills, mulga ranges and flats—57,000,000 acres (page 167).

(b) Regions without general development of hardpan—40,000,000 acres:

20. Gascoyne region: red and brown stony soils of hilly formations carrying mulga, grasses, etc.—13,500,000 acres (page 168).

21. Minilya region: red and brown soils of a sandhill formation ~~and coastal~~ country—7,400,000 acres (page 168).

22. Ashburton region: red and brown soils transitional with the semi-desert steppe zone—spinifex hills, mulga slopes and valley grasslands—19,100,000 acres (page 169).

E. *Zone of brown acidic soils of the spinifex semi-desert steppes of the north-west*—36,600,000 acres (page 170).

23. Nullagine region: dissected plateau country carrying spinifex, grasses and scattered small trees—13,300,000 acres (page 171).

24. Warralong region: rolling plains and valleys carrying spinifex, grasses and various trees—6,800,000 acres (page 171).

25. Hamersley region: dissected tableland country—coastal grasslands, hilly spinifex country and valley grasslands—10,600,000 acres (page 173).

26. Lyndon region: undulating spinifex grasslands—5,900,000 acres (page 173).

F. *Zone of pinkish brown calcareous soils of the Nullarbor Plain desert shrub steppes*—16,900,000 acres (page 174).

27. Nullarbor region: sparse salt bush and blue bush plain—16,900,000 acres (page 174).

G. *Zone of pinkish brown calcareous soils of the acacia semi-desert scrub, mallee and salt bush-blue bush associations*—31,000,000 acres (page 175).

28. Giles region: sandhills and plains fringing the Nullarbor plain in Western Australia—31,000,000 acres (page 175).

H. *Zone of brown soils of the northern tropical woodlands, savannahs and grasslands*—79,600,000 acres (page 176).

29. Fitzroy region: soils of the main valleys and highly eroded plateaux—39,900,000 acres (page 181).

30. Hann region: rough, dissected, sandstone tableland largely of grey skeletal soils and characterised by a savannah woodland—28,900,000 acres (page 184).

31. Brockman region: high rainfall, coastal extension of the sandstone table-land with river gorges carrying rain forests—5,000,000 acres (page 184).

32. Drysdale region: similar to the Hann region but characterised by much ironstone, gravelly soil and sclerophyll forest—5,800,000 acres (page 184).

I. *Zone of red sands of the central desert sandhills*—143,000,000 acres (page 184).

33. Carnegie region: spinifex covered sandhills broken by ranges associated with belts of mulga, desert eucalypts, etc.—143,000,000 acres (page 185).

As far as possible, pertinent, available chemical data with respect to the soils of the several zones have been summarised in distribution and other tables (Tables 15, 16 and 17). This information is imperfectly treated on account of lack of sufficient time to determine weighted averages for each horizon of each site examined. It was necessary to consider each sample, and

not each horizon from each site, as a unit in the preparation of these tables. This treatment will not be as accurate as may be desired but the distribution figures will certainly show clearly the general chemical composition of Western Australian soils.

TABLE 15.

Distribution table showing the Phosphate and Potash status of Soils of Western Australia by Zones.

(Compiled from information obtained from Files 96/06, 2700/09, 238/17 and 2148/22 of the Department of Agriculture, Files 252/15, 52/18 and 23/20 of the Explosives and Analytical Department, Western Australia, Simpson & Teakle (1934), Teakle & Southern (1935), Hosking & Greaves (1936), Hosking & Burvill (1938), Kessell & Stoate (1938), Serial Nos. A2062–2076, and data from the Lake King and Salmon Gums soil surveys.

A.—PHOSPHORIC OXIDE (P_2O_5).

(Soluble in concentrated hydrochloric acid.)

Range—per cent. P_2O_5.		Number of Samples in each Range.						
		below ·01	·01—·02	·02—·04	·04—·06	·06—·08	·08—·10	above ·10
A.—Grey, yellow and red podsolised, or leached, soils	Surface	38	59	66	50	24	16	29
	Subsoil	**52**	**39**	**35**	**27**	**14**	**2**	**9**
B.—Red, brown earth zone	Surface	2	16	28	7	2	2	1
	Subsoil	**2**	**17**	**10**	**1**	....	....	....
C.—Grey and brown calcareous solonised soils	Surface	15	16	14	3	5	1	1
	Subsoil	**42**	**17**	**7**	**10**	**3**	**1**	....
D.—Red and brown acidic soils of the acacia semi-desert scrub	Surface	....	....	2	2	....	6	5
	Subsoil	....	....	....	**2**	**3**	**4**	**1**
E.—Brown acidic soils of semi-desert steppes		....	1	6	4	1	....	1
H.—Brown soils—Fitzroy region		....	4	4	8	2	....	4
Sand and gravel heath and wodjil soils	Surface	....	5	1	....	....	....	....
	Subsoil	....	5	4	....	....	....	....

B.—POTASH (K_2O).

(Soluble in concentrated hydrochloric acid.)

Range—per cent. K_2O.		Number of Samples in each range.							
		below ·01	·01—·03	·03—·05	·05—·10	·10—·30	·30—·50	·50—1·0	above 1·0
A.—Grey, yellow and red podsolised, or leached, soils	Surface	23	55	33	66	41	6	5	4
	Subsoil	**26**	**28**	**25**	**43**	**22**	....	**6**	**4**
B.—Red brown earth zone	Surface	1	5	6	25	12	7	4	....
	Subsoil	....	....	**4**	**6**	**16**	....	**5**	....
C.—Grey and brown calcareous, solonised soils	Surface	....	4	3	7	13	8	11	8
	Subsoil	....	**5**	....	**7**	**10**	**5**	**31**	23
D.—Red and brown acidic soils of the acacia semi-desert scrub	Surface	....	....	....	....	4	6	5	....
	Subsoil	....	....	....	....	**2**	**2**	**7**	....
E.—Brown acidic soils of semi-desert steppe		....	....	1	....	5	2	....	....
H.—Brown soils—Fitzroy region		....	4	2	3	3	9	....	....
Sand and gravel heath and wodjil soils	Surface	....	1	1	3	1	....	....	....
	Subsoil	....	....	**2**	**3**	**2**	**2**	....	....

TABLE 16.

Distribution Table showing the Nitrogen and Calcium Status of Soils of Western Australia by Zones.

(Compiled from information obtained from Files 96/06, 2700/09, 238/17 and 2148/22 of the Department of Agriculture, Files 252/15, 52/18 and 23/20 of the Explosives and Analytical Department, Western Australia, Simpson & Teakle (1934), Teakle & Southern (1935), Hosking and Greaves (1936), Hosking & Burvill (1938), Kessell & Stoate (1938), Serial Nos. A2062–2076, and data from the Lake King and Salmon Gums soil surveys.)

A.—Total Nitrogen.

Range—per cent. N		Number of Samples in each Range.						
		Below ·01	·01—·03	·03—·05	·05—·10	·10—·30	·30—·50	Above ·50
A.—Grey, yellow and red podsolised, or leached, soils	Surface	1	16	21	70	96	24	10
	Subsoil	**16**	**81**	**51**	**39**	**10**	....	....
B.—Red brown earth zone	Surface	....	3	6	27	17	....	....
	Subsoil	....	**11**	**14**	**8**	....	....	....
C.—Grey and brown calcareous, solonised soils	Surface	....	18	11	14	12	....	....
	Subsoil	**3**	**56**	**25**	**9**	....	....	....
D.—Red and brown acidic soils of the acacia semi-desert scrub	Surface	....	2	4	10	3	....	....
	Subsoil	....	**7**	**3**	**1**	....	....	....
E.—Brown acidic soils of semi-desert steppes		....	2	4	7	1	....	....
H.—Brown soils—Fitzroy region		3	1	2	7	6	2	1
Sand and gravel heath and wodjil soils	Surface	....	4	2	....	....	....	....
	Subsoil	....	7	2	....	....	....	....

B.—Calcium (CaO).
(Soluble in concentrated hydrochloric acid.)

Range—per cent. CaO		Number of Samples in each Range.							
		Below ·10	·10—·50	·50—1·0	1·0—2·0	2·0—5·0	5·0—10·0	10·0—20·0	Above 20·0
A.—Grey, yellow and red podsolised, or leached, soils		105	125	17	9	4	1	....	....
B.—Red brown earth zone		22	32	4	1	3	3	2	1
C.—Grey and brown calcareous, solonised soils	Surface	11	18	2	2	6	....	....	....
	Subsoil	**11**	**11**	**3**	**3**	**7**	**7**	**8**	....
D.—Red and brown acidic soils of the acacia semi-desert scrub		1	3	4	....	....	....	....	....
E.—Brown acidic soils of semi-desert steppes		1	3	4	2	3	....	....	....
H.—Brown soils—Fitzroy region		5	4	2	1	3	1	2	1

Study of these data show the great variability of the soils of Western Australia. Some are exceptionally rich in most of the important constituents. The majority are exceptionally low in phosphate and the general response of pastures and crops to superphosphate suggests that the phosphate present is also of low availability. Western Australian soils are generally low in nitrogen and organic matter, apparently the result of the arid summer conditions and the type of native vegetation not favouring organic matter accumulation. In the heavier textured soils of the wheat belt and in orchards in the wetter districts, the nitrate-nitrogen status appears to be good. The woodland soils of the wheat belt are generally rich in potash but the light textured soils are less generously supplied although actual potash deficiency

TABLE 17.

Analyses of soils from wet and dry areas in the agricultural districts of Western Australia.

Data from Dr. Howell's Report.

—	—	—	Analyses—per cent. in the soil.								
			Humus.	Nitrogen.	P_2O_5.	K_2O.	available.		CaO.	$CaCO_3$.	NaCl.
							P_2O_5.	K_2O.			
Wet Areas	Surface ...	11 Samples ...	2·83	·151	·051	·114	·009	·016	·348	·251	·023
	Subsoil ...	15 Samples ...	1·22	·055	·035	·157	·003	·014	·180	·149	·016
Dry Areas ... ... (including sandplain and white gum soils)	Surface ...	15 Samples ...	·77	·051	·028	·307	·002	·020	·598	·769	·010
	Subsoil ...	24 Samples ...	·51	·031	·028	·416	·002	·027	2·727	4·729	·077

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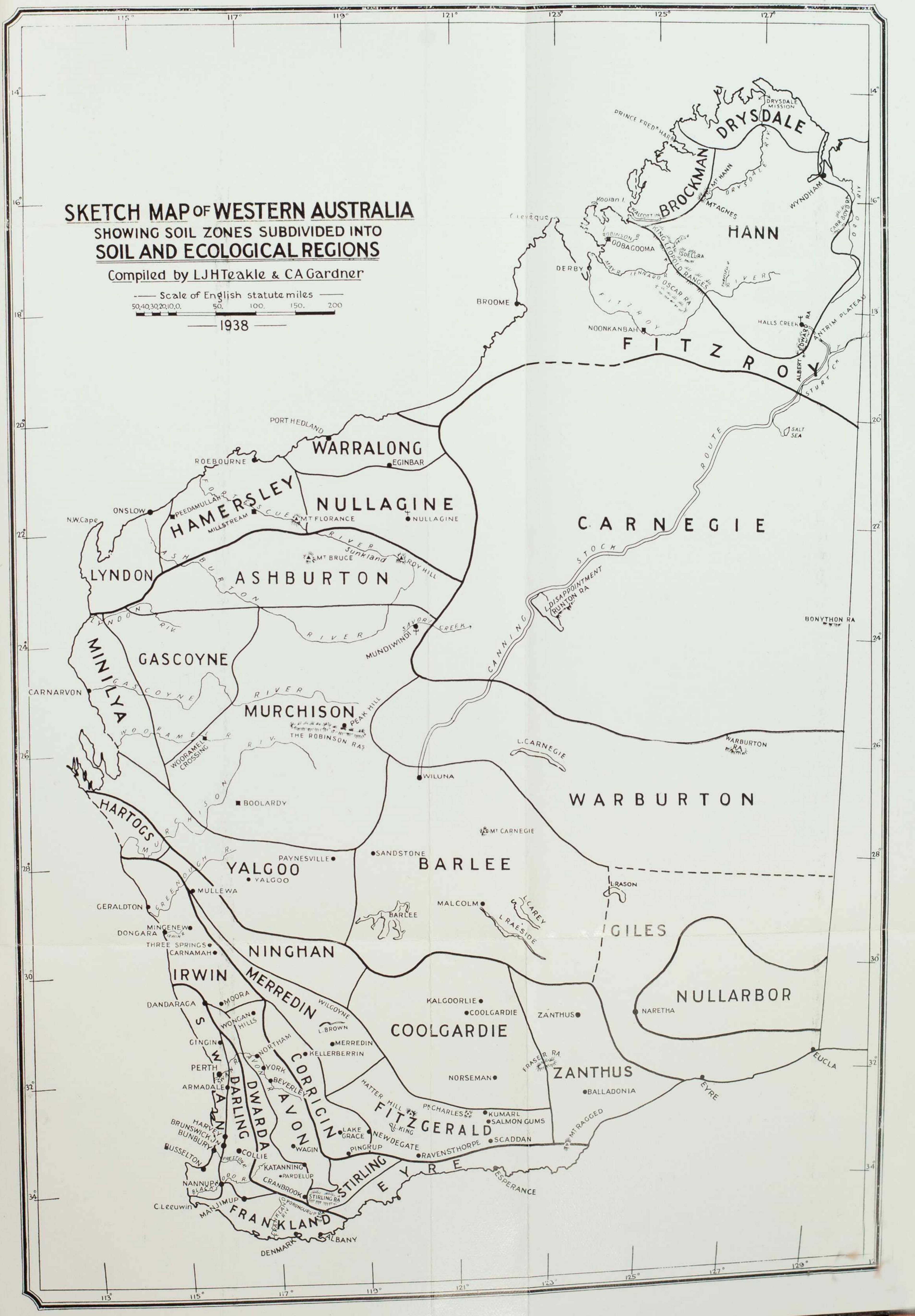
SKETCH MAP OF WESTERN AUSTRALIA
SHOWING SOIL ZONES SUBDIVIDED INTO
SOIL AND ECOLOGICAL REGIONS
Compiled by L J H Teakle & C A Gardner
Scale of English statute miles
50 40 30 20 10 0 50 100 150 200
1938
DRYSDALE
BROCKMAN
HANN
FITZROY
WARRALONG
HAMERSLEY
NULLAGINE
CARNEGIE
LYNDON
ASHBURTON
MINILYA
GASCOYNE
MURCHISON
WARBURTON
HARTOGS
YALGOO
BARLEE
GILES
NINGHAN
IRWIN
MERREDIN
NULLARBOR
COOLGARDIE
SWAN
DARLING
DWARDA
AVON
CORRIGIN
ZANTHUS
FITZGERALD
STIRLING
EYRE
FRANKLAND
WYNDHAM
DERBY
BROOME
HALLS CREEK
PORT HEDLAND
ROEBOURNE
ONSLOW
CARNARVON
WILUNA
GERALDTON
PERTH
BUNBURY
ALBANY
ESPERANCE
KALGOORLIE
COOLGARDIE
NORSEMAN
EUCLA

GENERAL INDEX.